Chapter 13
Utilization of oil palm co-products as feeds for livestock in Malaysia

M. Wan Zahari,[1] A.R. Alimon[2] and H.K. Wong[3]
[1] Universiti Malaysia Kelantan (UMK), Locked Bag 36, Jalan Pengkalan Chepa, Kota Bharu, Kelantan, Malaysia
[2] Universiti Putra Malaysia (UPM), 43400, UPM Serdang, Selangor, Malaysia
[3] Malaysian Agricultural Research and Development Institute (MARDI), Mail bag 12301, GPO 50774 Kuala Lumpur, Malaysia
E-mail for correspondence: wanzahari@umk.edu.my

ABSTRACT

Several oil palm industry co-products can be utilized as animal feed, notably oil palm fronds (OPF), oil palm trunks (OPT), palm press fibre (PPF), empty fruit bunches (EFB), palm kernel cake (PKC) and palm oil mill effluent (POME). These co-products are obtained either during the harvesting of the fruits, or the extraction and refining of crude palm oil (CPO) or palm kernel oil (PKO). Many of the co-products from the plantation (field residues) and processing mills need further processing before they can be used effectively in livestock diets.

Information on chemical composition, nutritive values, improvement methods and feeding response of ruminants fed oil-palm co-product-based diets are widely documented. Besides livestock feeds, some co-products are also utilized in the manufacturing of industrial products and organic fertilizers. OPF has been successfully utilized as feedstuffs either freshly chopped, as silage, or processed into pellets and cubes. Optimum inclusion level in beef and dairy animals is about 30 percent. Ensiled OPT produced reasonably good liveweight gain (LWG) of about 0.7 kg/day in beef cattle when fed at levels between 30 and 40 percent. PPF has a lower digestibility, which limits its inclusion in ruminant diets to less than 20 percent. PKC is a high-energy source and is a cost-effective ingredient in ration formulations for various livestock species. Beef and dairy production utilizing PKC-based diets are more economical under local dietary and management systems than non-PKC-based diets. High content of fibre and shell can limit use in poultry and aquaculture. With biotechnological treatments, inclusion levels of PKC can be increased to 30 percent for poultry feeding. POME, the residue left from the purification of CPO, can be combined with PKC and OPF to provide a cost-effective and complete ration for feeding ruminant livestock. The use of EFB, the material remaining of fruit bunches after steaming, is very limited and is generally utilized only after irradiation and culture-substrate treatments. The utilization of other locally available oil-palm-based co-products is targeted at increasing dietary energy content and improving nutrient digestibility. These include palm-fatty acid distillates (PFAD) and CPO, which are more suited for supplementing dairy animals, poultry, swine and aquaculture. The use of spent bleaching earth (SBE), another co-product from the oil-palm refineries, is very limited at present. Improvement in feed conversion efficiency (FCE) and maximizing the use of local feedstuffs represents a potential area of application to reduce the high cost of feed in Malaysia, especially in the non-ruminant subsector.

INTRODUCTION

The oil palm industry has become the backbone of Malaysia's economic and social development. It is developing rapidly to meet high global demand for palm oil, oleo-chemicals and biodiesel. In 2008, Malaysia produced about 17.74 million tonne of palm oil from over 4.49 million hectare of planted area. Palm oil and palm kernel oil (PKO) contributed about 30 percent of the total global production of oils and fats in 2008 (Oil World, 2009). The plantation area has increased from 97 000 ha in 1965 to 4.5 million ha in 2008. The planted area in Peninsular Malaysia, Sabah and Sarawak were 2.41, 1.33 and 0.74 million ha, respectively (MPOB, 2009). The private-estate sector occupied the largest area, amounting to about 60 percent of the total area. The rest of the estates were government and state-schemes (28 percent) and smallholders (12 percent). The government-owned plantations include the Federal Land Development Authority (FELDA), the Federal Land Consolidated Authority (FELCRA), the Rubber Industry Development Authority (RISDA) and the State Economic Development Corporation (SEDC). Of the government-owned plantations, FELDA is the largest owner of oil palm land. As of 2009, there were 252 oil palm mills and 36 refineries in Peninsular Malaysia, 117 oil palm mills and 11 refineries in Sabah, and 41 oil palm mills and 5 refineries in Sarawak. Over the period 1990–2005, the land area under oil palm increased by 6.6 percent per

MAIN MESSAGES

- **A large percentage of available palm kernel cake (PKC) should be efficiently used for domestic use as the main energy and protein sources for feeding ruminant and non-ruminant animals.**
- **Oil palm frond (OPF) is a good fibre source for ruminant feeding, and it is available in Malaysia throughout the year.**
- **Complete diets based on oil-palm co-products can be produced for various livestock species, including for aquaculture. Recommended levels of PKC feeding are 30–80 percent for growing beef cattle and 20–50 percent for goats, while for lactating dairy cattle it is 20–50 percent. Recommended levels of PKC in feed for poultry and freshwater fish are no more than 10 percent. The optimum level of OPF in feed for ruminant animals is 30 percent.**
- **Use of various oil-palm co-products as sources of feed for ruminants raised on the plantation itself is to be encouraged and maximized in order to reduce production costs.**
- **There is a huge potential – currently underestimated – for developing integrated oil palm-based ruminant production in Malaysia.**

year, compared with negative growth for rubber, cocoa and coconut areas (MPOA, 2005).

Oil palm, *Elaeis guinensis* Jacq, has an economic life of 20 to 25 years and annually bears 8 to 12 fruit bunches, each weighing between 15 and 25 kg. Each fruit bunch carries 1000 to 3000 fruits, and each palm tree produces about 40 kg of palm oil annually. In palm oil milling, when the fresh fruit bunches (FFB) are processed, the economic end products are crude palm oil (CPO) and palm kernel oil (PKO). In the oil palm industry, the co-products are obtained from two sources, namely from residues in the plantations (field residues) and from palm oil milling. The former produces two major co-products: oil palm trunks (OPT) and oil palm fronds (OPF), while the latter produces empty fruit bunches (EFB), palm kernel cake (PKC), palm oil mill effluent (POME), palm press fibre (PPF), and shell. After processing some of the co-products are suitable for use as animal feed ingredients. The availability of various type of biomass and wastes in the oil palm environment has been intensively reviewed (Zin, 2000). A more recent paper estimated yields of 0.62, 0.04, 0.96 and 0.23 t/ha/year for OPF, PKC, POME and PPF, respectively (Devendra, 2006).

This present paper describes the utilization of the biomass from plantation and milling activities as feeds for livestock. Emphasis is placed on resources with abundant supply and easy to collect and utilize for livestock feeding. Selected products from refining activities that are used as high-energy sources for dairy animals, poultry, swine and aquaculture are also highlighted.

CO-PRODUCTS FROM OIL PALM PLANTATIONS (FIELD RESIDUES)

Oil palm fronds

Availability

Oil palm fronds (OPF) are obtained during harvesting or pruning and felling of palms for replanting. As such, it is available throughout the year. On an annual basis, about 24 fronds are pruned per palm tree, and the weight of fronds varies considerably with age of the palm, with an average annual pruning of 82.5 kg of fronds per palm (Chan, 1999; Chan, Watson and Kim, 1981). At the time of felling during land clearing for replanting, each crown gives approximately 115 kg of dry fronds. It is estimated that about 30 million tonne of OPF is produced on a dry matter (DM) basis annually during the pruning and replanting operations (Ma, 2000) . Traditionally, most OPF is left to rot between the rows of palm trees, mainly for soil conservation, erosion control and ultimately for the long-term benefit of nutrient recycling. However, due to the need to increase the net return per hectare, OPF has been used as resource material for extraction of vitamin E, paper pulp and animal feed. The large quantity of fronds produced by a plantation each year makes this biomass a very promising source of roughage for ruminants.

Nutritive value

OPF comprises three main components: a petiole, rachis and leaflets. About 70 percent of the DM in the OPF is from the petiole, and the rest from leaves and rachis. The leaves contain a higher percentage of crude protein (CP) and ether extract (EE) than the petioles. The DM content of OPF is about 31.0 percent and *in vitro* digestibility of DM of leaves and petioles is uniform throughout the length of the fronds, with a mean value of 35.6 percent (Ishida and Abu Hassan, 1992). OPF also contains between 15 and 26 percent hemicellulose, depending on its age. The moisture contents of chopped fresh OPF, solar-dried chopped OPF, steam-dried ground OPF and OPF pellets were 58.6 percent, 44.6 percent, 12.7 percent and 14.7 percent, respectively, with respective density values of 0.27, 0.08, 0.12 and 0.53 (Oshibe *et al.*, 2001). The chemical composition of OPF in comparison with other oil-palm co-products is shown in Table 1.

Rumen degradability is an appropriate assessment of the nutritive value of a fibrous feed for ruminants because

TABLE 1
Mean chemical composition (percent in dry matter, except for ME) and nutritive value of oil palm frond and other oil palm co-products

Co-products	CP	CF	NDF	ADF	EE	Ash	ME (MJ/kg)
Palm kernel cake (PKC)	17.2	17.1	74.3	52.9	1.5	4.3	11.13
Palm oil mill effluent (POME)	12.5	20.1	63.0	51.8	11.7	19.5	8.37
Palm press fibre (PPF)	5.4	41.2	84.5	69.3	3.5	5.3	4.21
Oil palm fronds (OPF)	4.7	38.5	78.7	55.6	2.1	3.2	5.65
Oil palm trunks (OPT)	2.8	37.6	79.8	52.4	1.1	2.8	5.95
Empty fruit bunches (EFB)	3.7	48.8	81.8	61.6	3.2	–	–

Notes: CP = crude protein; CF = crude fibre; NDF = neutral-detergent fibre; ADF = acid-detergent fibre; EE = ether extract; ME = metabolizable energy. *Sources:* Wong and Wan Zahari, 1992; Wan Zahari *et.al.,* 2000.

TABLE 2
Rumen degradation parameters of whole and different fractions of oil palm frond (OPF) on incubation in nylon bags and using the equation $p = a + b(1-e^{-ct})$

Incubation (hours)	Petiole	Leaflet	Midrib	OPF
a (g/kg)	21.2	21.7	14.4	18.4
b (g/kg)	24.7	46.1	28.3	38.3
c (% per h)	2.8	1.2	1.5	2.5
(a+b)	45.8	67.8	42.7	56.7

Notes: p = actual degradation at time t; a = intercepts; b = insoluble but potentially degradable component at time t; c = rate of constant of b; (a+b) = total degradability. *Source:* Islam *et al.,* 1997.

it relates to the availability of nutrients. Table 2 shows the degradation characteristics of different fractions of OPF. A degradability value of 40 percent or more at 48 hours incubation indicates that OPF could be fed directly to ruminants. However, some improvement in terms of nutritive value is needed to increase the degradability level further. The characteristics of rumen degradation, digestibility, voluntary intake and palatability of several types of processed OPF have been reported by Kawamoto, Wan Zahari and Oshio (1999).

Nutritive value improvement

Several processing techniques have been developed to improve the feeding qualities of OPF. These include urea and molasses treatments, preservation as silage, alkali treatment, and steaming under high temperature and high pressure (Table 3), pelletizing and enzymatic degradation. Urea- and molasses-treated OPF can almost meet the maintenance requirements of ruminants for energy and protein. The optimum level of urea inclusion in the OPF based diet was 30 g/kg ration, and steaming was reported to increase OPF digestibility. Increasing the level of urea in the steamed OPF resulted in reduced dry matter intake (DMI) and dry matter digestibility (DMD). A recent study revealed that microbial fermentation of OPF mixed with rice bran and rice husk through microbial fermentation of Japanese koji (*Aspergillus oryzae*) enhanced the feeding value by improving the CP content, reducing the NDF and improving the DMD of the feed, particularly with *Aspergillus awamori* (Ramli *et al*., 2010).

Freshly chopped

Freshly chopped OPF has been extensively used by local farmers for feeding to beef and dairy cattle in Malaysia. The growth performance and carcass composition of Brahman-Australian Commercial Cross (ACC) beef cattle fed iso-nitrogenous diets based on a freshly chopped OPF and PKC-based mixture is shown in Table 4. Diet 3 (40% OPF + 60% PKC) was the most economical as indicated by feed cost per weight gain value. Better feed conversion efficiency (FCE) and average daily gain (ADG) were obtained by diet 5 (20% OPF + 80% PKC), but it was not economical in terms of cost. Moreover, there were higher percentages of fat in the carcass. Carcass weight and dressing percentage improved with increasing levels of OPF in the diet.

TABLE 3
Chemical composition of oil palm fronds (OPF), untreated and steam-processed at various pressures (% in DM)

Treatment	NDF	ADF	HC	ADL	NDS	Ash	CP
Untreated	70.9	44.1	26.8	8.5	29.1	4.5	4.3
Fresh, steamed							
10 kg/cm^2	60.7	52.2	8.5	18.9	39.3	4.4	4.3
12.5 kg/cm^2	59.8	49	10.8	15.7	40.2	4.6	4.5
15 kg/cm^2	65.8	51.2	14.6	17.7	34.3	4.7	4.5
Pre-dried, steamed							
10 kg/cm^2	59.8	50.1	9.7	19.9	40.2	4.7	4.2
12.5 kg/cm^2	58.3	48.3	10	18	41.7	4.7	4.3
15 kg/cm^2	56.1	53.3	2.8	20.9	43.9	4.8	4.3

Notes: DM of the untreated and treated materials were almost similar, between 93.2 and 94.0; NDF = neutral-detergent fibre; ADL = acid-detergent fibre; HC = hemicellulose; ADL = acid-detergent lignin; NDS = neutral-detergent solubles (%NDS = 100 - %NDF); CP = crude protein. *Source:* Bengaly *et al*., 2000.

TABLE 4
Growth performance and carcass composition of Brahman-Australian Commercial Cross beef cattle fed mixtures with varying ratios of fresh chopped oil palm frond (OPF) and palm kernel cake (PKC)

Parameter	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5
OPF	60%	50%	40%	30%	20%
PKC-based mixture	40%	50%	60%	70%	80%
Number of animals	24	24	24	24	24
Initial LW (kg)	289.8	279	284.4	279	278.9
Final LW (kg)	340.2	327.5	343	343.5	356.9
ADG (kg/day)	0.64	0.61	0.67	0.75	0.85
DMI (kg/head/day)	6.12	6.02	6.5	7.08	7.56
FCR	9.56	9.87	9.7	9.44	8.89
Feed cost	3.09	3.11	3.04	3.45	3.23
Carcass composition					
Dressing %	54	56.3	54.8	57.8	57.2
Meat to bone ratio	2.9	2.57	2.88	3.03	2.85
Meat (% carcass weight)	66.6	57	59.3	55.7	55.6
Bone (% carcass weight)	22.7	21.9	20.9	18.7	19.5
Fat (% carcass weight)	9.6	14.2	14.7	17.2	17.2

Notes: The diets were iso-nitrogenous diet (with about 16.4% CP). The PKC-based mixture contained soybean meal, vitamin-mineral premix and urea. All animals were fed palm fatty acid distillates (PFAD) at 3% of DMI as an energy source. Feed cost is based on Ringgit/kg gain over an 86-day experimental period (US$ 1 = Ringgit 3.8). CF percentages in diets 1 to 5 were 31.5, 28.6, 25.6, 22.2 and 19.2, respectively. The respective percentage total digestible nitrogen (TDN) values were 58.2, 60.2, 62.3, 65.3 and 67.3. CP = Crude protein; CF = Crude fibre; LW = Live weight; ADG = Average daily gain; DMI = Dry matter intake; FCR = Feed conversion ratio. *Source:* Mohd. Sukri *et al.,* 1999.

It is evident that the demand for processed OPF began to increase after the ensilation and pelletizing processes were introduced, especially when storage and ease of handling became necessary for commercial farms. However, in some locations, there was no urgent requirement to conserve OPF for silage as fresh OPF is abundantly available throughout the year.

Preservation as silage

Whole OPF can be chopped (to about 2–3 cm in length) and conserved as silage, and can be kept for several years when properly stored. Many trials were carried out to study the effect of additives on silage quality. These include treatment with water, molasses and urea (Table 5). The results indicate that good quality silage could be produced without no additives, provided that OPF was ensiled under anaerobic conditions. Urea addition at the rate of 1–2 percent prevented mould growth, and delayed the initiation of heat production by 28 hours. Inclusion of more than 3 percent of urea reduced the nutritive value of the silage. However, no adverse effect on animals was observed when urea was used at 3 percent (Table 6). Current research shows that *Lactobacillus plantarum,* heterofermentative lactic acid bacteria, is the best isolate for OPF silage, based on its ability to decrease pH faster and attain the lowest pH compared with other isolates (Hussin and Wan Mohtar, 2010).

TABLE 5
Effect of water, molasses and urea addition at ensiling on the fermentation characteristics of oil palm frond silage

Parameter	Treatment			
	Control	Water	Molasses	Urea
pH value	4.02 b	3.93 b	3.93 b	7.38 a
Organic acids (% DM)				
Lactic acid	1.89 bc	2.30 b	3.55 a	1.51 c
Acetic acid	0.89 b	0.65 b	0.78 b	8.99 a
Butyric acid	1.07 b	0.99 b	1.04 b	1.66 a
Percentage spoilage	13.9 a	9.0 a	1.6 a	0.0 b

Notes: Control had no additives. a, b, c = means with different letters in a row differ ($P < 0.05$).
Source: Abu Hassan and Ishida, 1992.

Processing of pellet and cube

Digestibility studies conducted using mature Kedah-Kelantan (KK) bulls indicated a DMD value of about 45 percent for OPF silage. It was significantly reduced when urea was included at 6 percent of the total diet (Ishida and Abu Hassan, 1992). Further long-term feeding trials were conducted with growing and finishing beef cattle and with lactating cows (Abu Hassan *et al.,* 1993; Ishida *et al*., 1994). In the trial without urea, the feed required for LWG and lean meat production was reduced with higher inclusion levels of OPF silage (Table 7). This is reflected in reduced feed cost.

The potential of OPF silage as a source of roughage for lactating dairy cows is shown in Table 8. The cows fed 30 percent OPF silage produced more milk than those fed 50 percent OPF silage. There were no adverse effects on the animals, milk yield or flavour, even when the level of OPF silage was increased to 50 percent. In a separate study, the LWG of swamp buffaloes fed 30 percent OPF silage was comparable to those fed 50 percent sago meal (Shamsudin, Mohd. Sukri and Abdullah Sani, 1993). Studies with sheep indicated that OPF silage was better utilized compared with nipa palm (*Nypa fruticans*) frond silage. Additionally,

TABLE 6
Effect of urea level at ensiling on chemical composition, fermentation characteristics, voluntary intake and digestibility of oil palm frond silage

Parameter	Urea level (% in DM)		
	0	3	6
Chemical composition			
Dry matter (%)	30.1 ab	30.7 a	28.6 b
Percentage of dry matter			
Crude protein	6.7 c	11.4 b	17.2
Organic cell contents	20.8 a	20.0 ab	13.0 c
NDF	73.2 b	73.9 b	80.3 a
Fermentation characteristics			
pH value	3.78 a	4.89 b	7.81 c
Total acids (DM percent)	3.68 b	4.76 b	8.96 a
Composition of acids (%)			
Lactic acid	91.0 a	37.4 b	13.0 c
Acetic acid	6.1 c	25.8 b	72.9 a
Propionic acid	0.1 b	3.8 a	0.8 b
Butyric acid	0.9 c	30.9 a	6.7 b
Ammonia (% DM)	0.0 c	0.6 b	1.1 a
Voluntary DM intake (g/day)			
Digestibility (%)	39.9 a	32.1 a	24.0 b
Dry matter	45.3	46.8	35.7
Organic cell contents	**100**	**91.7**	**86.1**
NDF	29.1	37.5	30.2
TDN (DM%)	45.5	49.2	37.5

Notes: DM = dry matter; NDF = neutral-detergent fibre; TDN = total digestible nutrient; a, b, c = means with different letters in a row differ (P <0.05). *Source*: Ishida and Abu Hassan, 1992.

TABLE 7
Effect of oil palm frond levels on growth performance and carcass characteristics of Australian commercial cross bulls

Parameter	Treatment			
	T1	T2	T3	T4
Live weight (kg)				
Initial weight	229.1	226.5	232.9	229.4
Final weight	396.3 a	336.4 ab	333.8 b	357.2 ab
Daily gain (kg/day)	0.75 a	0.62 ab	0.45 c	0.57 bc
Feed intake (kg DM/day)	7.02 a	6.10 ab	5.48 b	5.58 b
Carcass weight (kg)	237.2 a	210.2 ab	189.0 b	195.2 b
Weight of carcass components (kg)				
Meat	127.8	121.5	107	116.7
Fat	76.4 a	58.1 ab	45.8 b	46.0 b
Bone	37.6	33.4	33.2	36.1
% in carcass				
Meat	35.6	58.2	57.2	59.2
Fat	31.6 a	27.6 ab	24.2 b	23.7 b
Bone	16	16.1	17.7	18.4

Notes: T1 = 10% Urea OPF silage + 90% PKC-based concentrate. T2 = 30% Urea OPF silage + 70% PKC-based concentrate. T3 = 50% Urea OPF silage + 50% PKC-based concentrate. T4 = 50% OPF silage only + 50% PKC based concentrate. a, b, c = means with different letters in a row differ (P <0.05). PKC = Palm kernel cake. *Source*: Ishida *et al.,* 1994.

TABLE 8
Effect of feeding oil palm frond silage on performance of Sahiwal-Friesian lactating dairy cows

Parameter	Dietary treatment		
	T1	T2	T3
Number of cows	9	9	9
Body weight (kg)	417	451	450
Ingredient composition of diet (% DM)			
OPF silage	30	50	–
Fodder	-	-	50
Concentrates	70	50	50
Feed intake and milk production			
DM intake (kg/day)	6.46 b	5.86 c	8.28 a
Yield of 4% FCM (kg/day)	6.93	5.73	6.48
4% FCM to ME intake ratio (kg/MJ)	0.109 a	0.088 b	0.096 b

Notes: T1 = 30% OPF silage diet. T2 = 50% OPF silage diet. T3 = 50% fodder diet. FCM = fat corrected milk. ME = metabolizable energy. Concentrates contained 24.0% CP and 11.3 MJ/kg of ME. a,b,c = Means with different suffixes differ (P <0.05). *Source*: Abu Hassan *et al.,* 1993.

the provision of molasses was reported to increase the potential degradability of both nipa and oil palm fronds (Abdalla *et al.,* 2001). In this trial, ammonia-N in the rumen liquor of the animals fed OPF supplemented with 0 percent and 30 percent molasses were found to be conducive for optimum rumen environment, with values of 141.5 mg/litre and 142.9 mg/litre, respectively. These values were, however, lower than suggested levels of 200–250 mg/litre for ruminants (Preston and Leng, 1997).

Feeding beef cattle

The effects of varying levels of OPF pellet on intake and growth performance of local beef cattle has been reported by Oshibe *et al.* (2000). The trial was conducted to evaluate the effect of OPF-based diets varying in CP content on intake and growth performance of growing Charolais × KK crossbred cattle. The animals were fed iso-caloric pelleted diets (containing about 9.13 MJ/kg DM) based on ground OPF at a 30 percent inclusion level. Over the 172-day feeding period, the LWGs achieved were 0.50, 0.52, 0.30 and 0.44 kg/day, respectively, when the animals were fed 10, 12, 14 and 15 percent CP (Table 9). The respective mean DMDs of the diets were 55.7, 68.6, 56.8 and 52.7. The LWGs obtained were comparable to those raised on 30 percent roughage and 70 percent concentrate. Provision of 12 percent CP improved DMD by about 23 percent compared with those fed 10 percent CP. Further addition of protein increased neither intake nor DMD, as shown in the groups fed higher CP levels. What contributed to the differences was not clear, as energy contents among the diets were very similar. It is unlikely that this is due to small differences in CF content as the values from the four diets only varied between 20.5 and 23.3 percent. Levels of EE for all of the diets were below 5 percent, and hence unlikely to cause any significant impairment in CF digestibility for pelletized diets based on OPF. Body scoring of cattle fed 30 percent OPF-based diets was from medium to good. Meat quality was excellent, with less deposition of fat in the carcasses. Irrespective of protein levels, the ranges for carcass weight and mesenteric fat were from 130.9 to

TABLE 9
Intake and growth performance of beef cattle raised on OPF pellet based diet

Treatment	Mean DMI (kg/day)	DM digestibility (%)	Initial LW (kg)	Final LW (kg)	LWG (kg)	Mid-abdomen (cm)
10% CP	6.40	55.7	242.5	328.5	0.50	181–214
12% CP	5.94	68.6	234.8	324.0	0.52	172–226
14% CP	5.88	56.8	231.5	283.4	0.30	182–192
15% CP	5.94	52.7	236.6	312.6	0.44	171–212

Notes: DMI = dry matter intake; LW = live weight; LWG = live weight gain; CP = crude protein.
Source: Wan Zahari *et al*., 2000, 2002.

215.3 kg and 5.0 to 6.6 kg, respectively. The meat to bone ratio ranged from 0.7:1 to 3:1.

Distended rumen was reported in beef heifers fed pellets made from ground OPF at a 30 percent inclusion level (Wan Zahari *et al.,* 2002). This is associated with the rapid rate of passage of finely ground materials from the pellet, which is unfavourable for optimum rumen fermentation. Faster passage of feed through the rumen is known to depress DMD. Hence, rumen retention time should be reduced to stimulate better digestibility. Longer particle size (>15 mm) should be considered for making complete diets based on OPF. One option to make OPF cube, a process that does not require grinding (Hayakawa and Ariff, 2000). Small particle size of the diet is also known to depress the population of protozoa in the rumen, but what particle size is best for the protozoa to stimulate optimum fermentation is another issue. A high protozoan population density could also increase requirements for supplementary protein. Additionally, reducing the protozoan population in the rumen generally increases animal productivity on low-protein diets. Moreover, an optimal ratio of nitrogen to sulphur is vital for efficient ruminal microbial growth for diets based on fibrous materials like OPF. Contrary to what has been thought, distension of the rumen was not associated with bolus formation, which has been found in growing sheep raised on OPF silage and urea molasses mineral blocks (Wan Zahari, unpublished). Irrespective of the treatments, there seemed to be large variations between animals for the weight of the rumen, intestine and other organs (Table 10). There were also no abnormalities with regard to the structural and physical appearances of organs and other body tissues. The meat and organs were safe for consumption and of superior quality due to less deposition of body fat (Wan Zahari *et al.*, 2000, 2002). The average concentration of lead (Pb) residues in OPF feed was lower than the concentration specified for the maximum residual limit level (3000 ppb) (Faridah *et al.*, 2002).

The LWG of Brahman × KK male cattle fed diets containing 70 percent OPF + 30 percent cassava fodder was significantly less than for those fed 70 percent OPF + 30 percent concentrate or 70 percent OPF + 15 percent cassava fodder + 15 percent grain concentrates (Tung *et al.*, 2001). The values for DMI (kg/head/day), N retention (% of N intake) and LWG (g/head/day) for the respective treatments were 4.01, 4.78 and 4.66; 15.49, 19.04 and 17.93; and 277.8, 412.7 and 373.0 respectively.

TABLE 10
Body composition of beef cattle raised on oil palm fronds based diet

Parameter	Bulls	Heifers
Live weight before slaughter (kg)	274.0–407.0	186.0–238.0
Carcass weight (hot) (kg)	130.9–215.3	98.7–136.4
Rumen weight (empty, kg)	7.5–10.4	4.2–5.8
Intestinal weight (full, kg)	10.85–13.30	8.0–11.0
Intestinal weight (empty)	6.0–9.0	3.8–7.0
Liver (kg)	2.15–4.40	1.92–3.96
Spleen (kg)	0.758–1.172	0.71–1.82
Kidney (kg)	0.508–0.714	0.175–0.304
Mesenteric fat (kg)	5.00–6.60	2.60–5.50
Fat in carcass (kg)	3.50–10.10	1.52–4.47
Sirloin (kg)	1.36–3.40	0.74–2.00
Loin (kg)	2.60–9.30	2.52–4.10
Meat:Bone ratio	2.70–3.10	2.42–3.10

Notes: The animals were Kedah-Kelantan × Charolais crosses. Source: Wan Zahari *et al*., 2000, 2002.

Feeding dairy cattle

Research and development on OPF feeding for dairy cattle reflects the intensive system of rearing that is suitable for Malaysia, considering the high cost of pasture land. Several experiments have been conducted that were aimed at developing feeding programmes based on OPF pellets or OPF cubes.

A study was conducted to evaluate ground OPF-based diets as a complete ration for lactating Sahiwal-Friesians dairy cows. The lactation performance and LW change of the animals fed 30 percent OPF pellet ration is shown in Table 11. Milk yields of cows used in this experiment varied from 11.1 to 20.3 L/day for the duration of the trial. The highest recorded 28-day milk yield period was 609 litres, equivalent to an average daily yield of 21.75 litres. The overall milk fat was 3.5 percent, and daily supplementation with 100 g long hay was insufficient to increase the fat content to the level of 4.6–4.8 as obtained when feeding concentrate-grass mixture or dairy cattle pellets (Abu Bakar *et al.,* 2001).

TABLE 11
Effects of oil palm frond (OPF)-based pellets on milk yield and milk composition

Ration	Milk yield (L/28 days)	Milk fat (%)	Milk protein (%)	Weight change (kg)
30% OPF pellets	366	3.5	3.5	22.5
30% OPF pellets + LG	375	3.5	3.5	16.5

Notes: LG = Unchopped guinea grass hay given at 100 g/cow/day as long fibre supplement. Four Sahiwal-Friesian cows per group, assigned to a treatment sequence in a 4×4 Latin square design involving four 28-day measurement periods following a 2-week adjustment period. Daily ration fed to each cow was limited to 14 kg/day. *Source*: Abu Bakar *et al.,* 2001.

In a separate study, Sahiwal-Friesian heifers fed molasses-treated OPF were observed to consume 30 percent more (P <0.05) total feed DM compared with untreated-OPF (Abu Bakar *et al.,* 2000). The improvement in intake could be attributed to improvement in the palatability and digestibility of nutrients. There was no obvious advantage of brine treatment (salty water containing 39.12 percent sodium chloride by weight, commonly used for food preservation) in stimulating intake of OPF pellets. LWGs of the animals fed molasses-treated OPF were comparable to those fed brine-treated OPF, with values of 0.69 kg/day and 0.68 kg/day, respectively. In comparison, Sahiwal-Friesian heifers fed maize stover silage and guinea grass produced gains of 0.43 and 0.47 kg/day, respectively (Abu Bakar, Aminah and Mansor, 1990). In addition, Friesian heifers fed complete rations based on 70 percent sugarcane bagasse as roughage recorded mean LWG between 0.38 and 0.56 kg/day, depending on quality of the energy-protein sources used (Van Horn *et al.,* 1980). Dried grated coconut meal (containing 64 g CP/kg; 359 g CF/kg; 24 g EE/kg; and 10.8 MJ ME/kg) and PKC are equally good as supplemental feed with OPF pellets for growing Sahiwal-Friesian heifers diets, provided that the protein content is enriched (Abu Bakar *et al.,* 1999).

Oil palm trunks

Availability

Oil palm trunk (OPT) is only available after oil palms are felled for replanting at an age of about 25–30 years (Mohamad *et al.,* 1986). The main economic criteria for felling are the height of palms exceeding 13 m, and annual yield of bunches falling below 10–12 t/ha. The biomass consists mainly of vascular bundles and parenchyma tissues. The parenchyma recovery is about 38 percent (Oshio *et al*., 1991).

Nutritive value

The nutritive value of OPT is similar to PPF. It contains about 3 percent CP. The vascular bundles contain less lignin than the parenchyma tissues and in digestibility studies with sheep the parenchyma tissue had higher DM and organic matter values.

Processing and livestock feeding

OPT can be collected and processed into chips (about 2–3 cm) and preserved in the form of silage. Vertical or bunker concrete silo are recommended. OPT silage can be utilized for feeding after 21 days in the silo. OPT silage results in excellent fermentation due to low pH (3.2) and good production of lactic acid. Without any treatment, the DM digestibility of OPT is comparable to rice straw. Feeding trials with ACC beef cattle showed that OPT silage produced better FCE than rice straw, with good rate of growth and eating quality (Oshio *et al*., 1991). The DMD of OPF silage without urea was 45 percent, compared with 44.2 percent and 35.8 percent when urea was added at 3 percent and 6 percent, respectively. Insecticide residues were not detected in the OPT samples (Ong and Abu Hassan, 1991).

The parenchyma is an excellent source of roughage for beef cattle in feedlots. The biomass was readily consumed by the animals, even at 50 percent level. It can be integrated with OPT fibre processing where the fibre can be used for production of pulp, paper and composite panels. The nutritive value of the material can be further enhanced by physical, chemical or biological treatment. OPT-based ration can be formulated for feeding large ruminant animals and the maximum level of inclusion is suggested to be 30 percent.

CO-PRODUCTS FROM OIL PALM MILLING

Palm kernel cake

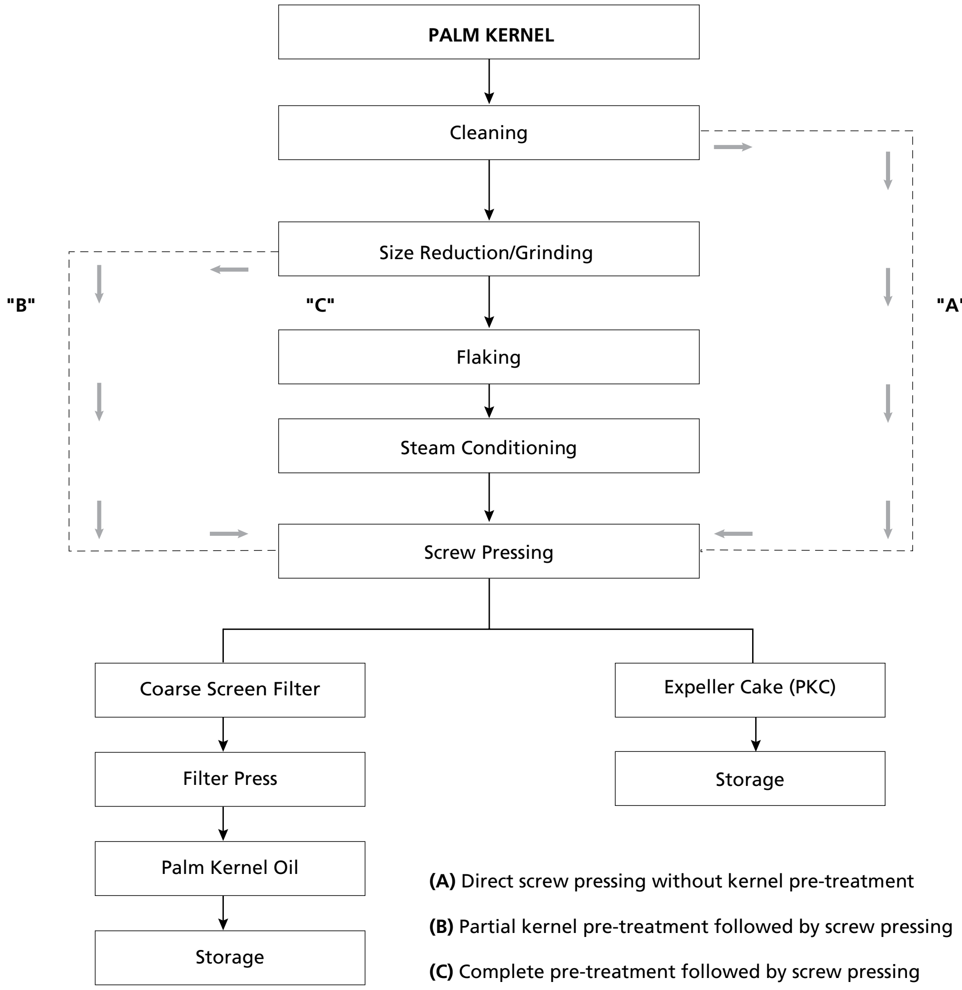
Availability

Palm kernel cake (PKC) is an important feed for livestock in Malaysia. It is produced after the extraction of PKO from the kernels of the oil palm fruits. PKC is also known as palm kernel meal (PKM), or palm kernel expeller (PKE) (Figure 1). Two types of oil extraction process are employed, either screw press (expeller) or solvent extraction. The oil milling industry differentiates PKC as the solvent extraction type, while PKE is the screw-pressed type. PKE is subject to heat damage during screw pressing. More than 99 percent – over 2 million tonne – of the meal produced is PKE, of which 95 percent is exported, mainly to the European Union. In this paper, the term PKC is used as it is accepted widely in Malaysia and other countries.

Nutritive value

In general, the solvent extracted PKC has a lower oil content, ranging from 1.2 to 5.0 percent, while the expeller pressed PKC has 4.5 to 17.3 percent (Tang, 2000). Generally, PKC can be classified as an energy-feed (Table 12) and its chemical composition is somewhat similar to copra meal, rice bran or corn gluten feed. The ME values for ruminants and poultry are 10.5–11.5 MJ/kg and 5.9–7.0 MJ/kg, respectively (Yeong, 1985). The ME for swine is generally higher than for poultry, with the values between

FIGURE 1
Flow chart of the mechanical extraction of palm kernel oil



Sources: MPOB, 1992; Tang, 2000

10.0 and 10.5 MJ/kg. The CP content is considered to be more than sufficient to meet the requirement of most ruminants. PKC has a good amino acid profile (Table 13), with availability between 62 and 87 percent (Yeong, Mukherjee and Hutagalung, 1981). Limiting amino acids are lysine, methionine and tryptophan. The protein quality of the MPOB-Q-PKC, recently introduced by the MPOB is superior to the existing PKC (Atil, 2009). This product is obtained after pre-processing the palm nuts to remove completely the shell and the fibrous testa of the kernels. However, this product is still under development. PKC also contains high residual fat (about 10 percent), carotene and vitamin E (about 0.3 IU/kg), which can act as a natural antioxidant. Table 14 shows the fatty acid content in PKC. Its low content of unsaturated fatty acids also reduces rancidity problems.

PKC is high in minerals, with P and Ca contents of 0.48 to 0.71 percent and 0.21 to 0.34 percent, respectively (Table 15). The Ca:P ratio is very low (about 0.36:1) and

TABLE 12
Chemical composition and nutritive value of palm kernel cake

Parameter	
Dry matter (DM as %)	88.0–94.5
Chemical composition (% in DM)	
Crude Protein (CP)	14.5–19.6
Crude Fibre (CF)	13.0–20.0
Ether extract (EE)	2.0–8.0
Ash	2.0–10.0
Nitrogen-free Extract (NFE)	46.7–75.8
Neutral-detergent Fibre (NDF)	66.8–78.9
Oil content (%) +	4.5–17.3
Shell and dirt	3.6–21.4
Metabolizable energy (MJ ME/kg)	
Ruminants	10.5–11.5
Poultry	6.5–7.5
Swine	10.0–10.5

Notes: Oil content values adapted from from Siew, 1989.

TABLE 13
The amino acid profile of palm kernel cake

Amino acid	Composition (%)
Alanine	0.92
Arginine	2.18
Aspartic acid	1.55
Cystine	0.2
Glycine	0.82
Glutamic acid	3.15
Histidine	0.29
Isoluecine	0.62
Leucine	1.11
Lysine	0.59
Methionine	0.3
Phenylalanine	0.73
Proline	0.62
Serine	0.69
Threonine	0.55
Tyrosine	0.38
Valine	0.93
Tryptophan	0.17

Notes: The concentration values are based on total protein content in palm kernel cake of 16.01%. *Source*: Yeong, 1983.

TABLE 14
The fatty acid content of palm kernel cake

Fatty acids	g/100 g oil
C6:0	0.2
C8:0	3
C10:0	4
C12:0	48
C14:0	16
C16:0	8
C18:0	3
C18:1	15.4
C18:2	2.4
C20:0	0.1

Source: MPOPC, 1995.

TABLE 15
The mineral content of palm kernel cake

Element	Level
Calcium (Ca) (%)	0.21–0.34
Phosphorus (P) (%)	0.48–0.71
Magnesium (Mg) (%)	0.16–0.33
Potassium (K) (%)	0.76–0.93
Sulphur (S) (%)	0.19–0.23
Copper (Cu) (ppm)	20.5–28.9
Zinc (Zn) (ppm)	40.5–50.0
Iron (Fe) (ppm)	835–6130
Manganese (Mn) (ppm)	132–340
Molybdenum (Mo) (ppm)	0.70–0.79
Selenium (Se) (ppm)	0.23–0.30

Source: Alimon, 2004.

diets based on PKC need to be supplemented with Ca to meet animal requirements. The level of Mg, K, S, Zn, Fe, Mn, Mo and Se are within acceptable ranges. However, Cu content in PKC (21–29 ppm) is higher than

TABLE 16
The digestibility coefficients of nutrients in palm kernel cake

Nutrient	Sheep	Cattle
Dry matter	0.70	0.76
Crude protein	–	0.78
Ether extract	0.91	0.84
Ash	–	0.67
Neutral-detergent fibre	0.52	0.76
Acid-detergent fibre	0.53	0.73

Source: Wong and Wan Zahari, 1997.

required by ruminants. More than 75 percent of PKC is cell wall component, which consist of 58 percent mannan, 12 percent cellulose and 4 percent xylan (Mohd. Jaafar and Jarvis, 1992). Table 16 shows the average digestibility coefficients of nutrients in PKC, based on studies with sheep and cattle. The digestibility values for ADF and NDF are much higher in cattle than in sheep, suggesting that sheep are less efficient than cattle in digesting fibre. The digestibility of NDF in forage hays are also higher in cattle than in sheep (Reid *et al.*, 1990). Earlier studies suggested that differences in the concentrations of urea and sulphur in blood, and lower excretion of N, P and Ca by the cattle, could have increased microbial activity in the rumen and digestion of fibre (Playne, 1978)..

PKC is normally free from aflatoxin, and therefore very safe for livestock feeding. It is also free from any chemicals, heavy metals, pesticides and dioxins. High DM content inherent in the PKC discourages growth of micro-organisms and mould, and it can therefore be stored for periods of up to three months without much problem.

Livestock feeding.

Feeding beef cattle and swamp buffaloes

PKC is widely used as the main ingredient in rations for feedlot cattle and buffaloes. In Malaysia, feedlot cattle are normally fed diets containing up to 80 percent PKC, with LWG of 0.6–0.8 kg/day for local KK cattle and 1.0–1.2 kg/day for crossbred cattle (Wan Zahari *et al.*, 2000). Diets containing almost 100 percent PKC have been fed to feedlot cattle with no negative effects, provided that the supply of Ca and vitamins (in particular A and E) are sufficient to meet requirements. Studies have shown that supplementing traditional rations of beef cattle with 30–50 percent PKC increased LWG (Wan Zahari and Alimon, 2004). It is common practice in Malaysia to produce complete feed based on PKC, either in the form of pellets, cubes or as total mixed ration (TMR) (Wan Zahari, Wong and Hussain, 2009). Apart from PKC, other common ingredients that are included in TMR include rice bran, brewers grain, palm oil mill effluent (POME), tapioca waste, urea, salt and minerals (Wan Zahari *et al.*, 2003). An example of the formulation for beef cattle feeding is PKC (80%) + grass/hay (17.5%) +

limestone: (1.5%) + mineral premix (1.0%). A low cost fattening programme for beef cattle can be developed based on PKC and PPF, with LWG between 0.60 and 0.75 kg/day (Wan Zahari *et al*, 2000)

Owing to its small particle size, the level of PKC in beef cattle diets should not be more than 85 percent to avoid occurrence of metabolic problems such as acidosis and kidney stones. Grass or hay or other long-fibre sources should be included at at least 10 to 15 percent in the total ration. Addition of grasses or other forages will reduce the rate of passage of PKC in the gastro-intestinal tract of the animals, thus increasing retention and digestibility of nutrients (Oshibe *et al.*, 2001; Wan Zahari *et al.,* 2002). Moreover, when feeding PKC at high levels, attention should be given to Ca supplementation (Wan Zahari and Alimon, 2004). Limestone (calcium carbonate) is the most appropriate Ca supplement as it is cheap and easily available. It is important to ensure that the ratio of Ca to P in the rations is within the range of 1:1 to 3:1 in order to preclude skeletal deformities and mineral imbalances. Sodium chloride and vitamin A should be supplemented at the appropriate levels to meet requirements. Feeding PKC at 100 percent inclusion level may cause wet faeces and digestive disorders, and is contrary to principles of proper ruminant nutrition.

Feeding dairy cattle

In dairy cattle rations, PKC is used as a source of energy and protein at an inclusion level of 30–50 percent. PKC-based pellet is a common feed supplement for dairy cattle in Malaysia and it is usually fed together with grass and other concentrates (Abu Hassan, 2005; Abu Bakar *et al*., 2000). The grass to concentrate ratios fed are around 50–70 percent:30–50 percent (Abu Hassan *et al*., 1996). In the Malaysian environment, daily milk yields of 10–12 L/head can be achieved, and, with good formulation, higher yields can be expected (Wan Zahari *et al*., 2000). Other common ingredients in rations for dairy cattle are rice bran, brewers grain, palm oil sludge (POS) or POME, soybean waste, bakery waste, salt and minerals (Abu Bakar *et al.*, 2001). In some areas, grass and other forages high in protein are given *ad libitum*. An example of a dairy cattle formulation is PKC (50%) + molasses (5%) + grass/hay (42%) + limestone (1.5%) + mineral premix (1%) + common salt (0.5%) (Alimon, 2004). Most of the PKC exported to the European Union is used in dairy cattle rations, but the level of inclusion is known to be limited to 15 percent.

Feeding sheep and goats

Recommended maximum inclusion level of PKC in sheep rations is 30 percent. Long-term feeding of PKC at high inclusion level (>80 percent) can cause Cu toxicity in sheep, as sheep are known to be very susceptible to Cu poisoning (Hair Bejo *et al*., 1995; Al-Kirshi, 2004). Some sheep breeds (especially crossbreds) accumulate Cu in the liver, causing liver damage. Addition of 100 ppm of zinc sulphate or 5.2 mg/kg ammonium molybdate together with 440 mg/kg sodium sulphate in the rations can overcome the Cu toxicity problem (Hair-Bejo *et al*., 1995). Cu toxicity does not appear in cattle, buffaloes, goats and other animals, but long-term feeding of PKC can result in high levels of Cu concentrations in the liver. An example of a formulation for goats is PKC (50%) + grass/hay (30%) + rice bran (10%) + soybean meal (9%) + mineral premix (1%) (Wan Zahari and Alimon, 2003).

Feeding poultry

Owing to its high fibre content, non-starch polysaccharides and shell content, the use of PKC in poultry rations is very limited, with wide variation in the optimum inclusion level. The main difficulty is the origin and variation in the oil and shell content of the PKC used. Broiler chicken can tolerate up to 20 percent PKC in their diets without affecting growth performance and FCE (Yeong, 1987; Abu Hassan and Yeong, 1999. In layer rations, PKC can be included up to 25 percent without any deleterious effects on egg production and quality (Yeong, 1987; Radim *et al*., 2000). However, inclusion of PKC at levels greater than 20 percent was reported to reduce egg production and egg quality (Yeong *et al.,* 1981), although in another study reduced egg production was only observed at levels exceeding 40 percent (Onwudike, 1988).

Muscovy ducks can be fed PKE at the 30 percent level without any deleterious effects on performance (Mustafa *et al*., 2001). Low-shell PKC with higher energy and CP content is important to maximize utilization in poultry. However, high inclusion levels of PKC require supplementation with high levels of fat, making the rations economically uncompetitive in comparison with conventional maize-soya-based diets.

Current research focuses on enhancing the nutrient content of PKC for poultry. Topics include enzyme treatment and solid-state fermentation of the PKC. Enzymic depolymerization of PKC releases digestible sugars that will be fully absorbed and metabolized by poultry. Supplementation with specific enzymes can improve nutrient digestibility and has worked efficiently to break down mannans in PKC (Noraini *et al*., 2002; Saenphoom *et al*., 2010). Broilers can be fed diets containing 30 percent fermented PKC without any adverse effect on performance (Noraini *et al.,* 2008). Fermentation with *Aspergillus niger* was reported to increase the true metabolizable energy of PKC from 5.5 MJ ME/kg to 8.1 MJ ME/kg. *Aspergillus niger* up to generation F_6 can be used as inoculum for fermentation of PKC (Abdul Rahman *et al.,* 2010). Chemical treatment using sodium hydroxide and formaldehyde have also been investigated, but with variable results. Further research is required to enhance the nutrient content of PKC for poultry (Wong *et al*., 2009).

Feeding swine

PKC is also suitable for swine at an inclusion level ranging from 20 to 25 percent for growers and finishers. In some areas in Peninsular Malaysia, PKC is used at lower levels (between 5 and 10 percent). An example of a formulation for feeding swine is PKC (20) + maize (65.5%) + soybean meal (9.5%) + fish meal (3.0%) + dicalcium phosphate (1.5%) + mineral premix (0.2%) + common salt (0.3%) (Wan Zahari and Alimon, 2003). In Nigeria, PKC is fed to swine at levels ranging from 15 to 40 percent without no negative effects on performance (Codjo *et al.,* 1995).

Feeding in aquaculture

The availability of PKC in many tropical countries where aquaculture is practised has generated much interest in its potential use in fish diets. Early studies indicated that PKC can be tolerated up to 30 percent in catfish *(Clarias gariepinus)* and 20 percent in tilapia (*Oreochromis niloticus)* rations with no deleterious effects on growth and performance (Sukkasame, 2000). An example of a formulation for African catfish is PKC (30%) + fish meal (20%) + cassava flour (15%) + soybean meal (31%) + sago (1%) + mineral and vitamin (2%) + vegetable oil (1%). PKC pre-treated with commercial feed enzymes resulted in better growth and FCE than with raw PKC. The fermentation of PKC with *Trichoderma koningii,* a cellulolytic fungus, increased the CP content in PKC from 17 percent to 32 percent (Ng *et al.,* 2002). At a 40 percent feeding level of PKC, the rate of growth was reduced and this was not rectified with the addition of 1.2 percent dietary L-methionine (Ng, 2006). It is suggested that 30 percent is the maximum inclusion level for enzyme-treated PKC in tilapia diets. More R&D is needed to optimize the use of feed enzymes in PKC-based diets in order to reduce the cost of using imported maize as an energy source.

Table 17 shows the recommended levels of PKC in the feeds for beef cattle, dairy cattle, sheep, goats, poultry, swine and freshwater fish.

TABLE 17
Recommended levels of palm kernel cake in livestock feeds

Species	Recommended level (%)
Beef Cattle	30–80
Dairy Cattle	20–50
Sheep and Goats	20–50
Poultry – broiler	<10
Poultry – layer	<10
Swine	<20
Freshwater fish	<10

Source: Wan Zahari and Alimon, 2003.

Palm oil mill effluent and palm oil sludge

Palm oil mill effluent (POME) is a general description for the discharge from palm oil extraction in the mill. This is the residue left from the purification of the crude palm oil (CPO) and includes various liquids, dirt, residual oil and suspended solids, mainly cellulosic material from the mesocarp of the fruits. When fresh, it is in the form of a thick, brownish-yellow, colloidal slurry comprising about 95 percent water with an average pH of about 4.7 and biological oxygen demand of 25 000 mg/L (Ngan, 2000). Some mills may use decantation to complement the clarifier in order to reduce the volume of effluent by 10 to 20 percent. By using the decanter-drier system, a lighter co-product is recovered in the form of decanter solid. In order to avoid confusion, the term POME should be restricted to only the raw untreated effluent. The decanter solid is obtained when most of the solids in the effluent is removed before the waste water is discharged into the pond. The effect of different chemical treatments on the settling ability of POME has been reported (Hassan *et al*., 2001).

Availability

The average production of POME is 670 kg for every tonne of FFB processed. In 1997, Malaysia produced about 32 million tonne of POME from 290 mills.

Nutritive value

The material is characterized by high content of ether extract (11.7%), ash (19.5%) and medium CP content (12.5%) (Table 1). Wide variability in ash content and CP digestibility in POME results in widely different feeding values (Gurmit Singh, 1994). The content of CF, cellulose, NDF and gross energy (GE) are 20.1 percent, 20 percent, 63 percent and 8.37 MJ/kg, respectively.

POME is non-toxic as no chemical is added during the oil extraction process. It is rich in minerals and therefore suitable to be used as an organic fertilizer in crop cultivation. The average concentrations of Ca, P, K and Mg are 0.8, 0.3, 2.5 and 0.7 percent, respectively (Gurmit Singh, 1994). Ammonia N, B, Fe, Mn, Cu and Zn are 35, 7.6, 46.5, 2.0, 0.89 and 2.3 mg/litre, respectively (Ma and Ong, 1985).

Feeding ruminants

Feeding raw POME to growing sheep at levels ranging from 10–60 percent of the diet showed that the 10 percent level of inclusion gave the highest digestibility (Devendra and Muthurajah, 1976). However, an assessment of feeding value using sheep indicated that up to 40 percent POME can be used either alone in molasses-urea-based diets or when combined in equal proportions with PPF. Retardation in rate of growth and skeletal mineralization have been observed when POME was fed at the 100 percent level in dairy cattle. In this case, supplementation with protein, energy and minerals is necessary. The combination of POME and sago meal (40% POME + 45% sago meal) has successfully been used for feeding local sheep, with daily liveweight gains of 59.1–64.0 g in the males and 50.5–54.3 g in the females. Field trials with cattle on estates have shown improved LWG. Satisfactory gains of between 0.18–0.43 kg/day for buffaloes and 0.47–0.78 kg/day for cattle were obtained with POME, PPF and PKC-based diets (Dalzell, 1977).

Feeding non-ruminants

Most of the studies in poultry utilized the solid portion of POME, which was dehydrated mechanically in the raw or in fermented form, or in mixtures with other feed materials. Dehydrated POME was used to replace part of the protein and energy sources in poultry diets. LWG and FCE of birds were significantly lower when the POME level in the diet exceeded 15 percent. Supplementation of the diet with lysine and methionine did not reverse the situation. Meat to bone ratios were 3.1:1 to 3.4:1, whereas diets with 20 and 25 percent POME gave ratios of 2.6:1 to 2.8:1.

In a layer trial, the optimum dietary level of inclusion was 10 percent (Yeong, 1983). The average percent egg production, total egg mass and feed:gain ratio were 76.4 percent, 8.9 kg and 2.77:1, respectively, as compared with 77.9 percent, 9.2 kg and 2.52:1, respectively, for the maize-soybean control diet. Inferior results were apparent in those birds fed diets with more than 10 percent POME. The optimum POME levels in diets were 15 percent for broilers and 10 percent for layers. The levels have also been confirmed with studies with pigs. Local and Pekin ducks were able to utilize 10 percent POME efficiently without exhibiting any adverse effect on growth and FCE (Yeong, 1983).

There are several commercial feeds derived from POME, specifically developed to have a high protein content. Examples are Censor (Centrifugal solid recovery), Prolima and Central solids (Centriplus). Prolima was used in poultry diets as a protein source to replace soybean meal. This product contained 2.42 Mcal ME/kg, 43.3 percent CP, 7.6 percent CF, 12 percent EE and with an amino acid profile comparable to groundnut meal. The optimum level of Prolima inclusion in diets was 30 percent. At this level, the birds showed feed intake, LWG, FCE and carcass quality comparable to those fed with the maize-soybean control diet. The optimum level of Prolima inclusion in layer diets was 20 percent (Yeong *et al.*, 1980). The digestibility of lysine and methionine were 8.3 and 22.1 percent, respectively, for POME and 80.0 and 76.1 percent, respectively, for Prolima. POME has very low amino acid digestibility. Incorporating 14 percent of Centriplus solids in the diets of growing pigs resulted in a reduction in LWG, increased feed intake and poor FCE compared with pigs fed the control diet.

Two types of Censor meals, prepared by using cassava-PKC as absorbents or cassava-PKC-grass meal as absorbents for palm oil effluent, were used to replace maize at feeding levels of 25–100 percent for laying hens. Birds fed with both types of Censor meals showed adverse effects on egg production and feed efficiency. When Censor meals replaced 50 percent maize, the LWG and FCE were comparable to the control diet. Substitution of maize by 50 percent Censor in pigs increased feed intake without affecting LWG. No significant differences in carcass traits were found. Both Prolima and Centriplus were not commercialized due to high cost of production.

In a separate study, four types of processed oil palm slurry (OPS), using rice bran as an absorbent, were tested on the performance of broiler chicks. The dietary treatment did not have significant impact on feed intake, LWG or FCE. Carcass yields were similar and mortality was unaffected by the dietary treatments (Atuahene, Donkoh and Ntim, 2000). Improving the quality of POME in terms of uniformity and nutrient availability can help to upgrade its status as a feed ingredient for the poultry industry. A recent study revealed that through submergence fermentation and using selected yeast cultures, the CP value increased from 11.2 percent to 14.1 percent, with the highest digestible amino acid being phenylalanine (digestibility coefficient 0.705) and the highest percentage of digestibility improvement was for lysine (20.3 percent) (Jame'ah *et al.*, 2010).

Empty fruit bunches

Ripe fruit bunches are harvested at intervals of 10–14 days throughout the economic life of the palm. Each oil palm bunch usually weighs about 15–25 kg and, depending upon the age of the palm and variety, there is about 24 percent oil in the bunch. Empty fruit bunches (EFB) are the remains of the fruit bunches after the fruits have been stripped and sterilized, following the steaming process at the oil palm mill. It is in the form of stalks with empty spikelets, and is commonly used as a mulching material during the early stages of planting in the plantation, or as raw material for fibreboard.

Availability

The average production of fresh EFB is about 4.42 t/ha/year, which is equivalent to 1.55 t/ha/year of dried EFB (Chan, Watson and Kim, 1981). Burning of EFB is now prohibited by regulation to prevent air pollution.

Nutritive value

EFB contains about 50 percent CF, 3.5 percent lipid, 3.6 percent CP, 81.8 percent NDF and 61.6 percent ADF.

Processing and livestock feeding

Although large quantities of EFB are produced yearly, very limited research has been done on its use as feed for livestock. Early studies on the treatments of EFB by irradiation and substrate culture have met with limited success. EFB fermented by inoculating *Pleurotus sajor-caju* was found to be palatable to beef cattle (Mat Rasol *et al.*, 1993). At present, EFB is widely used as pulp for making paper, bunch ash after incineration, mulch and recycling of nutrients for oil palms, wood composite products and fibreboard. Intensive R&D is required to improve its value for feeding if EFB is to be utilized as a major ingredient in livestock rations. EFB is also used as a substrate for cellulose enzyme production by solid-state bioconversion.

Palm press fibre

Availability

Palm press fibre (PPF) is a fibrous co-product of crude oil extraction of the mesocarp. More than 12.2 million tonne of PPF is produced annually in Malaysia, at a rate of 2.70 t/ha.

Nutritive value

PPF has 5.4 percent CP, 41.2 percent CF and 26 percent lignin (Table 1).

Processing and livestock feeding

Due to its poor nutritive value, PPF is commonly used as fuel to generate heat for boilers, for making pulp and paper, roof tiles and fibreboard. Being highly lignified and fibrous, it is not commonly used as feed for livestock, and when fed to cattle its intake by the animal is low because of the poor digestibility (24–30 percent).

Based on balance trials on sheep, optimum DMD of PPF was obtained when it was fed at 30 percent level of inclusion. Several treatments have been applied to PPF to improve its digestibility and palatability. Alkali treatments using sodium hydroxide and calcium hydroxide have been used, but had little effect in enhancing the digestibility of PPF. Steaming at 15 kg/cm^2 for 10 minutes improved the organic matter digestibility (OMD) of untreated PPF from 15 percent to 42 percent. Higher OMD levels were achieved by explosive depressurization at 30 kg/cm^2 for 1 minute (OMD reaching 51.6 percent). Other researchers found no benefit from sodium hydroxide treatment and steaming in improving the digestibility of PPF.

Formulated feedlot rations containing 30 percent PPF fed to LID × Red Dane male calves produced an average LWG of 117 kg per animal during the 251-day feeding. Rations containing 50 percent PPF and 30 percent PKC for dairy cattle provided the cheapest source of energy compared with cattle pellets based on starch equivalent.

The widespread use of PPF is still constrained by its low digestibility and the potential problem of rumen impaction. Farmers operating in the vicinity of oil palm mills can utilize PPF, either fresh or ensiled, to some extent for feeding cattle, and thus reduce cost of feeding. However, it is advocated that the feeding level should be maintained at less than 30 percent. Further research on chemical and physical treatments are necessary to improve its utilization in livestock.

Crude palm oil

Availability

Crude palm oil (CPO) is extracted from the mesocarp of the fruit of the oil palm tree (Figure 2). The mesocarp comprises about 70–80 percent by weight of the fruit, and about 45–50 percent of this mesocarp is oil. Two co-products produced during the refining of CPO are palm fatty acid distillates (PFAD) and spent bleaching earth (SBE).

Nutritive value

Like all natural fats and oils, CPO comprises mainly mono-, di- and triglycerides. There are free fatty acids, moisture, dirt (about 0.25 percent) and minor components of non-oil fatty matter, collectively referred to as unsaponifiable matter. CPO has a deep orange-red colour due to the high content of carotenoids, and is a rich source of vitamin E (300–600 ppm), consisting of tocopherols and tocotrienols. The content of palmitic acid (C16:0, saturated) and oleic acid (C18:1, unsaturated) are quite high (about 37.0 percent and 47.0 percent, respectively). The B-carotene content is 54 g/100 ml of oil, and maximum fatty acid content is 5 percent. The pro-vitamin A activity is about 640 IU/g. CPO does not contain n-3 highly unsaturated fatty acids, which are required by marine species. The GE value is about 8500 Kcal/kg, equivalent to about 34 MJ/kg.

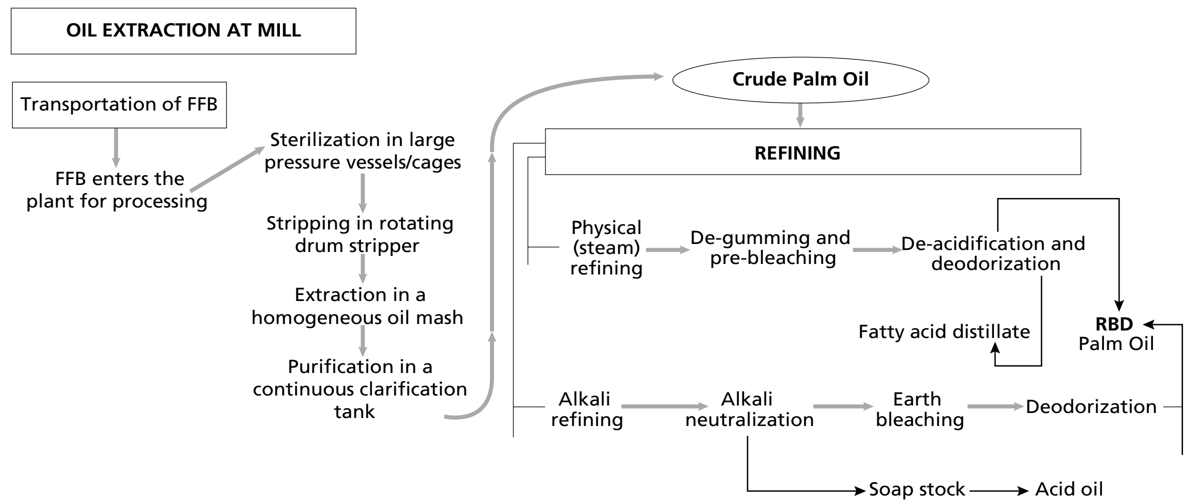
Livestock feeding

Palm oil is traditionally used at about 3 percent level in diets for pigs and poultry as a source of vitamins A and D, as well as to reduce dustiness of the diets. Higher levels of dietary palm oil of up to 10 percent have also been used successfully in diets for growing and finishing pigs in Malaysia. The percentage of lean cuts and backfat thickness increased with increasing levels of palm oil. In lactating cattle, supplementation with 2–8 percent of CPO increased both milk yield and milk fat content. The digestibility of CPO determined in balance trials with sheep gave a value of 85.4 percent. Information on the use of palm oil products in fish diets is currently limited to a few species only (Ng, 2010). About 90 percent of fish oil in the diets of catfish, *Hemibagrus bongan* (Popta 1904) (syn. *Mystus nemurus* (Valenciennes 1840)), could be replaced by CPO without affecting growth, FCE or body composition (Ng *et al.*, 2002). In another study, African catfish, *Clarias gariepinus*, was observed to show better growth when fed semi-purified diets containing 10 percent palm oil as the sole dietary lipid (Ng *et al*., 2004).

Palm fatty acid distillate (PFAD)

Palm fatty acid distillate (PFAD) is a co-product from refining of CPO at very high temperature (240–260 °C) under

FIGURE 2
Palm Oil Process Flow Chart



Source: MPOB, 2000

reduced pressure (2–6 mm Hg). Normally, the refinery mixes all the distillates, irrespective of whether from refining of CPO, crude palm olein or crude palm stearin (Figure 2). The final product is generally called PFAD. It is a light-brown solid at room temperature, melting to a brown liquid on heating.

Nutritive value

PFAD is composed of free fatty acids (81.7%), glycerides (14.4%), squalene (0.8%), vitamin E (0.5%), sterols (0.4%) and other substances (2.2%) (Ab Gapor, 2010). It is used in the animal feed, oleo-chemical and soap industries. Vitamin E, squalene and phytosterols are valuable constituents that can be extracted from PFAD and are of potential value for the nutraceutical and cosmetic industries.

Livestock feeding

Most of today's market for by-pass fats consumption is for dairy cow feed. High producing cows, especially in early lactation, are typically in negative energy balance. The loss in appetite and the effect on live weight caused by insufficient dietary nutrient intake to meet the demands of milk output subjects the high yielding cow to considerable weight loss over the first 60–80 days of lactation, and this can have substantial effects on subsequent performance. Consequently, the cow mobilizes body reserves such as body fat to meet the energy demand. Fats in their crude form have only limited application in ruminant feeds because they become hydrolyzed in the rumen into free fatty acids, which may cause many problems. The major problem is the tendency to reduce the rate and level of fibre digestion in the rumen. The maximum efficiency of milk production is achieved when fat contributes between 16 percent and 18 percent of the dietary ME intake.

There are several protected fats based on PFAD or calcium soaps that are marketed worldwide under various trade names. Most of the products are in the form of hydrogenated triglyceride with energy content of about 9000 Kcal/kg and a digestibility above 90 percent. The products can be absorbed in the small intestine and have a very low stearic acid (C-18:0) content of between 1 and 5 percent. Improved PFAD specifically derived from palm oil increased milk production and the total SNF of lactating cows (Farah Nurshahida *et al.*, 2008). The digestibility of fatty acids in hydrogenated distillate was lower than for Ca salts of fatty acids, but intake and production responses were similar or greater for diets containing hydrogenated distillate (Elliott, Drackley and Weigel, 1996). Calcium soaps of PFAD were satisfactorily stable till pH 5.5 in the rumen (Sukhija and Palmquist, 1990). Increasing dietary intake of Ca salts of PFAD resulted in increase ratio of $C_{18:1}$:$C_{18:0}$ in Holstein cows, but not in Jersey cows (Beaulieu and Palmquist, 1995). The use of PFAD is a practical and cost-effective way to produce high-energy diets without causing side effects due to increased lipids (Ng *et al.*, 2004)

Spent bleaching earth

In refining the CPO and PKO, Bleaching Earth is used to remove colour, phospholipids, oxidized products, metals and residual gums from the oil, impurities that can cause the oil to have an unattractive colour and taste. The residue is termed Spent Bleaching Earth (SBE). It absorbs approximately 0.5 percent by weight of the oil in the process. The SBE generated annually by Malaysian palm oil refineries is estimated to be approximately 120 000 tonne. Disposal of SBE by incineration, inclusion in animal feeds, as land fill or in concrete manufacturing is generally practised (Kheang *et al.*, 2006).

Nutritive value

The free fatty acid content of SBE ranges from 14 to 31 percent, with an unsaturated to saturated ratio of 46.5:53.5 (Lai, 1987). Apart from the original bleaching earth, the SBE also contains residual water, inorganic acids, organic acids, silicates and active carbon used in the refining process. The content of the output varies greatly, depending on the type of bleaching agents used and the method applied. Two main methods are chemical and physical refining. Chemical refining uses alkali to neutralize the free fatty acids, which are then removed as soap. Physical refining subjects the oil to steam distillation under high temperature and vacuum. Table 18 outlines the nutritive value of the SBE collected from a CPO refinery in Selangor, Malaysia (Wan Zahari, Mohd. Sukri and Wong, 2004). Ash content is excessively high, while the protein content is low (CP <6 percent). The heavy metal contents are within normal ranges and therefore SBE is considered safe for livestock consumption.

TABLE 18

Nutritive value and elemental composition of spent bleaching earth

Parameter	Value
Energy value	
Gross Energy (MJ/kg)	10.9
Proximate analysis (% DM)	
Ash (%)	57.9
CF (%)	1.0
CP (%)	0.44
EE (%)	14.6
ADF (%)	34.6
Heavy metal	
Cd (ppb)	44.35
Co (ppb)	4277
Cr (ppb)	43310
Mo (ppb)	Trace
Ni (ppb)	12229
Pb (ppb)	2001
Se (ppb)	Trace
Hg (mg/kg)	–
Major elements	
Ca (%)	6.28
K (%)	0.72
Mg (%)	2.44
Na (%)	0.70
P (ppm)	57.07
S (%)	0.42
Trace elements	
B (ppm)	2143
Cu (ppm)	8.61
Fe (ppm)	13.42
Mn (ppm)	217.50
Zn (ppm)	25.86

Source: Wan Zahari, Mohd. Sukri and Wong, 2004.

Livestock feeding

There is no published report on the utilization of SBE for ruminant livestock, even though the material is known to be used by small-scale farmers in certain areas in Peninsular Malaysia. Supplementation of protein is required if SBE is to be use as a main ingredient for ruminants. The high level of residual oil in SBE could be exploited for dairy feeding. Reflecting its high Ca content, SBE is suitable for combining with PKC in order to achieve a better Ca:P ratio. More studies need to be carried out to evaluate the effect of SBE on animal performance, especially on broiler and layer poultry. These should include studies to determine ME values and optimum inclusion levels. SBE can be further fortified or enriched with addition of certain nutrients or compounds to increase the feeding value. Apart from blending into animal feed, SBE can also be used as binder in feed processing, especially in diets with high fibre content, such as OPF-based diets. The free-flowing characteristic of SBE is very well suited for feed processing purposes and it can be pneumatically conveyed via a vacuum line.

MAXIMIZING LIVESTOCK PRODUCTION IN AN OIL PALM ENVIRONMENT

Of the land area under oil palm, only 2.1 percent is currently used for integration with ruminants, emphasizing the enormous potential for expanding this system (Devendra, 2011). The concept of integrating ruminants with tree crops is not new and has been practised with varying degrees of success. Grazing the undergrowth and providing supplementary feeding with feeds such as PKC and POME is economically feasible. The basic model for integrated systems involving cattle and oil palm has been intensively reviewed (Devendra, 2006; Devendra, 2007). Based on this model, theoretical calculations for a 500 000 ha oil palm plantation gives the following results:

- Carrying capacity utilizing native herbage alone at 4 kg DM/head/day = 214 286 head.
- Carrying capacity utilizing native herbage plus co-product feeds at 4 kg DM/day = 736 581 head (an increase of 245% over grazing alone).
- Using a 50 percent dressing percentage and a liveweight at slaughter of 420 kg, the quantity of beef produced using oil palm co-product feeds is 154 682 tonne.
- Annual gross revenue based on US$ 1260/t live weight = US$ 194.9 million.
- Rate of return on investment is from 8.1 percent for indigenous cattle to 16.3 percent from exotic cattle.

Lack of feeder cattle is one of the limiting factors in beef production in Malaysia. This is mainly associated with the high cost of rearing, as most of the feeder cattle are imported. It is estimated that about 1.8 million head of breeding females could be produced were the available feeds from 4.0 million hectare of oil palm to be effectively used, contributing about 0.5 million feeders per year. Based on these figures and assuming a 30 percent concentrate + 70 percent roughage ration is used for feeding, the total requirement for concentrate would be about 1.6 million tonne per year. About 78 percent of locally available PKC would be needed annually for beef production were it to be used in this way as the concentrate in the above feeding regimen, with OPF utilized as the main roughage source.

CONCLUSIONS

The rapid expansion of the palm oil industry in Malaysia has generated large quantities of wastes from the field and palm oil mill. Most of the wastes and residues are basically cellulosic and organic biomass with high nutrient content. Most of the resources can be used as feeds for livestock.

At the plantation site, potential feedstuffs include OPF and OPT, while co-products from the milling and refining activities include EFB, PPF, PKC, POME and SBE. The availability of these resources provides potential for more practical and cost-effective feeding systems, as feeding values and outcomes from the previous and current R&D activities are known. Significant development in the processing of these feedstuffs, either as an ingredient for total mixed rations or as complete and balanced feeds, would encourage further growth in the local goat, sheep, beef and dairy industry. Intensive rearing of beef cattle on oil palm plantations also offers tremendous potential for beef production in view of the availability of OPF, PKC, POME and SBE for use as feedstuffs. With changes in livestock production systems towards semi-intensive and fully intensive systems, the demand for feed is growing in Malaysia. Growth of the local livestock sector aims to meet the self-sufficiency level for beef and milk over the next decade, and this creates further demand for feed. It is also evident that these fibre sources are in high demand in markets in Japan, South Korea, Taiwan and the Middle East, in addition to the Malaysian domestic market. Promotion and marketing of the agro-industrial co-products from the oil palm industry should be intensified to further expand their use and commercial potential. CPO, PFAD and other specialty fats, though not usually categorized as oil palm co-products *per se*, have great potential to be utilized as energy sources for dairy animals, poultry, swine and in aquaculture. The utilization of oil palm co-products thus aims to convert the large plantation biomass not only into animal feed, but also into other commercially viable value-added products.

BIBILIOGRAPHY

Ab Gapor, M.T. 2010. Production of palm fatty acid distillate (PFAD). *Lipid Technology*, 22(1): 11–13.

Abdalla, S.A., Abdullah, N., Ho, W.Y., Liang, J.B. & Shamsudin, A.B. 2001. Degradation and rumen fermentation characteristics of frond silages in sheep. pp. 180–181, *in:* Proceedings of the 23rd Malaysian Society of Animal Production Annual Conference, 27–29 May 2001, Langkawi, Malaysia.

Abdul Rahman, A.R., Norlizawati, I., Jameah, H. & Ahmad, A. 2010. Evaluation of the performance of inoculums generation use for palm kernel cake fermentation. *In:* Proceedings of the 4th International Conference on Animal Nutrition, 21–23 September 2010, Johore Bahru, Malaysia.

Abu Bakar, C., Aminah, A. & Mansor, P. 1990. Effects of feeding ensiled maize stover on feed intake and live-weight changes in Sahiwal-Friesian weaners. *In:* Proceedings of the 13th Malaysian Society of Animal Production Annual Conference, Malacca, Malaysia.

Abu Bakar, C., Kamaluddin, H., Shamsudin, A.B. & Wan Zahari, M. 1999. Comparison of dried grated coconut meal and palm kernel meal as supplement to OPF pellets for intensive rearing of Sahiwal-Friesian heifers. pp. 281–283, *in:* Proceedings of the National Congress on Animal Health and Production, 3–5 September 1999, A' Farmosa Resort, Malacca, Malaysia.

Abu Bakar, C., Kamaluddin, H., Selamat, B. & Azahar, I. 2000. Maximizing intake of all oil palm (OPF) pellets by Sahiwal-Friesian replacement heifers reared under zero-grazing system of production. pp. 139–140, *in:* Proceedings of the 22rd Malaysian Society of Animal Production Annual Conference, 29 May–1 June 2000, Kota Kinabalu, Malaysia.

Abu Bakar, C., Yusof, S.M., Hayakawa, H., Wan Zahari, M. & Mohd. Sukri, I. 2001. Lactational responses of graded Sahiwal-Friesians fed pelleted OPF as complete feed. pp. 96–97, *in:* Proceedings of the 23rd Malaysian Society of Animal Production Annual Conference, 27–29 May 2001, Langkawi, Malaysia.

Abu Hassan, O. 1995. Processing and utilization of oil-palm biomass (by-products) for animal feed. pp. 197–207, *in:* Proceedings of the PORIM National Oil Palm Conference – Technologies in Plantation – The Way Forward, 11–12 July 1995, Bangi, Malaysia.

Abu Hassan, O. & Ishida, M. 1992. Status of utilization of selected fibrous crop residues and animal performance with special emphasis on processing of oil palm frond (OPF) for ruminant feed in Malaysia. *JIRCAS Tropical Agricultural Research Series,* 25: 134–143.

Abu Hassan, O. & Yeong, S.W. 1999. By-products as animal feedstuffs. pp. 225–239, *In:* S. Gurmit, K.H. Lim, L. Teo and David Lee, K. (Editors). *Oil Palm and the Environment – A Malaysian Perspective.* Malaysian Palm Oil Growers' Council, Kuala Lumpur, Malaysia.

Abu Hassan, O., Azizan, A.R., Ishida, M. & Abu Bakar, C. 1993. Oil palm fronds silage as a roughage source for milk production in Sahiwal-Friesian cows. *In:* Proceedings of the 16th Malaysian Society of Animal Production Annual Conference, Langkawi, Malaysia.

Abu Hassan, O., Ishida, M., Mohd. Sukri, I & Ahmad Tajuddin, Z. 1996. Oil palm fronds as a roughage feed source for ruminants in Malaysia. *FFTC Extension Bull,* No. 420. 8 p.

Alimon, A.R. 2004. The nutritive value of palm kernel cake for animal feed. *Palm Oil Developments. Malaysian Palm Oil Board,* 40: 12–16.

Al-Kirshi, R.A. 2004. The effect of molybdenum, sulphur and zinc supplementation on mineral balance in sheep fed palm kernel cake. M.Sc. thesis. Universiti Putra Malaysia.

Atil, O. 2009. Enhancing the MPOB-Q-Palm Kernel Cake in Poultry Diet, Animal Feedstuffs in Malaysia – Issues, Strategies and Opportunities. Malaysian Academy of Science, 57–67.

Atuahene, C.C., Donkoh, A. & Ntim, I. 2000. Blend of oil palm slurry and rice bran as feed ingredient for broiler chickens. *Animal Feed Science and Technology*, 83: 185–193.

Beaulieu, A.D. & Palmquist, D.L. 1995. Differential effects of high fat diets on fatty acid composition in milk of Jersey and Holstein cows. *Journal of Dairy Science,* 78(6): 1336–1344.

Bengaly, K., Liang, J.B., Jelan, Z.A., Ho, W.Y. and Ong, H.K. 2000. Effect of steaming conditions on nutrient contents and degradability of oil palm frond. pp. 189–190, *in:* Proceedings of the 22nd Malaysian Society of Animal Production Annual Conference. 29 May–1 June 2000, Kota Kinabalu, Sabah, Malaysia.

Chan, K.W. 1999. Biomass in the oil palm industry. pp. 41–53, *in:* S. Gurmit, K.H. Lim, L. Teo and K. David Lee (Editors). *Oil Palm and the Environment – A Malaysian Perspective.* Malaysian Palm Oil Growers' Council, Kuala Lumpur, Malaysia.

Chan, K.W., Watson, I. & Kim, L.C. 1981. Use of oil-palm waste material for increased production. pp. 213–241, *in:* Proceedings of the Conference on Soil Science and Agricultural Development in Malaysia. Malaysian Soil Science Society, Kuala Lumpur, Malaysia.

Codjo, A.B. 1995. Oil palm products and by-products for local swine in Benin West Africa. pp. 91–94, *in:* Y.H. Ho, M.K. Vidyadaran and M.D. Sanchez (Editors). Proceedings of the First Symposium on Integration of Livestock to Oil-palm Production. Malaysian Society for Animal Production.

Dalzell, R. 1977. A case study on the utilization of oil palm effluent by cattle and buffaloes. pp. 132–141, *in:* Proceedings of the Symposium on Feedingstuffs for Livestock in South East Asia. Kuala Lumpur, Malaysian Society of Animal Production.

Devendra, C. 2006. Strategies for intensive use of local feedingstuffs for large-scale economic beef production in Malaysia. pp. 97–105, *in:* Proceedings of the 2nd International Conference on Animal Nutrition. Malacca, Malaysia.

Devendra, C. 2007. Integrated tree crops-ruminant systems: Expanding the R&D frontiers in oil palm. pp. 5–22, *in:* Proceedings of the Workshop on Integrated Tree Crops-Ruminant Systems: Assessment of Status and Opportunities in Malaysia. Academy of Sciences, Malaysia.

Devendra, C. 2011. Integrated tree crops-ruminant systems in south east Asia: advances in productivity enhancement and environmental sustainability. *Asian-Australian Journal of Animal Sciences*, 24(5): 587–602.

Devendra, C. & Muthurajah, R.N. 1976. The utilization of palm oil by-products by sheep. Preprint 19-48, Malaysian International Symposium on Palm Oil Processing and Marketing. Kuala Lumpur, Malaysia.

Elliott, J.P., Drackley, J.K. & Weigel, D.J. 1996. Digestibility and effects of hydrogenated palm fatty acid distillate in lactating dairy cows. *Journal of Dairy Science,* 79(6): 1031–1039.

Farah Nurshahida, M.S., Osman, A., Jumardi, R., Mardhati, M. & Ahmad Rusdan, A.Z. 2008. Milk yield and milk sensory parameters of Jersey cattle fed improved MPOB-HIE vs calcium salts of fatty acids. pp. 153–154, *in:* Proceedings of the Third International Conference on Animal Nutrition, 29–31 July 2008, Hotel Equatorial, Bangi Selangor, Malaysia.

Faridah, S., Shirai, Y., Gayah, A.R. &. Oshibe, A. 2002. Determination of heavy metal (Pb) in processed feed from oil palm frond by atomic absorption spectrometry. pp. 83–84, *in:* Proceedings of the 24th Malaysian Society of Animal Production Annual Conference, 21–23 May, Penang, Malaysia.

Gurmit Singh. 1994. Management and utilization of oil palm by-products. pp. 19–48, *in:* Proceedings of the 3rd National Seminar on Utilization of Oil Palm Tree and Other Palms, Kuala Lumpur, Malaysia.

Hair-Bejo, M., Davis, M.P., Alimon, A.R. & Moonafizad, M. 1995. Chronic copper toxicosis: utilization of palm kernel cake in sheep fed solely on concentrate diets. pp. 155–159, *in:* Y.W. Ho, M.K. Vidyadaran and M.D. Sanchez (Editors). Proceedings of the First Symposium on Integration of Livestock to Oil Palm Production. Malaysian Society of Animal Production.

Hayakawa, H. & Ariff. M.O. 2000. OPF cubes as animal feed, a gift to the world from Malaysia. MARDI-JICA Project Report, no. 15.

Hassan, M.A., Phang, L.Y., Noraini, A.R., Sirai, Y., Arbakariya, A. & Mohamed Ismail, A.K. 2001. Effect of different chemical treatments on the settleability of palm oil mill effluent. *Pertanika Journal of Tropical Agricultural Sciences,* 24(2): 79–85.

Hussin, G. & Wan Mohtar, W.Y. 2010. Screening for specific lactic acid bacteria for oil palm frond silage. *In:* Proceedings of the 31st Malaysian Society of Animal Production Annual Conference, 6–8 June 2010, Kota Bharu, Malaysia.

Ishida, M. & Abu Hassan, O. 1992. Effect of urea treatment level on nutritive value of oil palm fronds silage in Kedah-Kelantan bulls. p. 68 (vol. 3), *in:* Proceedings of the 6th AAAP Animal Science Congress, AHAT, Bangkok, Thailand.

Ishida, M., Abu Hassan, O., Nakui, T. & Terada, F. 1994. Oil palm fronds as ruminant feed. *Newsletter for International Collaboration*, 2(1): 12–13. JIRCAS, Ministry of Agriculture, Forestry and Fisheries, Tsukuba, Japan.

Islam, M., Dahlan, I., Jelan, Z.A., & Rajion, M.A. 1997. Rumen degradation of different fractions of oil palm frond. pp. 147–149, *in:* Proceedings of the 19th Malaysian Society of Animal Production Annual Conference, 8–10 September 1997, Puteri Pan Pacific Hotel, Johore Bahru, Malaysia.

Islam, M., Dahlan, I., Jelan, Z.A. & Rajion, M.A. 1998. Effect of ensiling and pelleting on nutrient contents and degradability of oil palm (*Elaeis guinensis*) frond. *In:* Proceedings of the 20th Malaysian Society of Animal Production Annual Conference, Putrajaya, Malaysia.

Jame'ah, H., Noraini, S., Noraishah, M.N. & Norrizan, A.W. 2010. Apparent ileal digestibility of amino acids in POME and fermented POME. pp. 369–371, *in:* Proceedings of the 4th International Conference on Animal Nutrition, 21–23 September 2010, Johore Bharu, Malaysia.

Kawamoto, H.M., Wan Zahari, M. & Oshio, S. 1999. Digestibility and voluntary intake of treated oil palm fronds. MARDI-JICA Project Report, no. 8.

Kheang, L.H., Foon, C.S., May C.F. & Ngan, M.A. 2006. A study of residual oils recovered from spent bleaching earth: their characteristics and applications. *American Journal of Applied Sciences,* 3(10): 2063–2067.

Lai, T.K. 1987. Studies on spent bleaching earth: palm oil recovery. MSc Thesis. Universiti Sains Malaysia.

Ma, A.N. 2000. Management of palm oil industrial effluents. pp. 1439–1461, *in:* Y. Basiron, B.S. Jalani & K.W. Chan (eds). *Advances in Oil Palm Research,* Vol II. Malaysian Palm Oil Board.

Ma, A.N. & Ong, A.S.H. 1985. Pollution control in palm oil mills in Malaysia. *Journal of the American Oil Chemists' Society*, 62: 261–266.

Mat Rasol, A., Hassan, H.M., Mohd. Sukri, M., Wan Badrin, W.H., Tajuddin, O., Khomsaton, A.B., Ashmawati, K., Zal U'yun, W.M., Ishak, M., Kume, T. & Hashimoto, S. 1993. Radiation pasteurised oil palm empty fruit bunch fermented with *Pleurotus sajor-caju* as feed supplement to ruminants. *Radiation Physics and Chemistry*, 42(4-6): 611–616.

Mohamad, H., Halim, H.A. & Ahmad, T.M. 1986. Availability and potential of oil palm trunks and fronds up to year 2000. Palm Oil Research Institute of Malaysia (PORIM), Occasional Paper, no. 20. 17 p.

Mohd. Jaafar, M.D. & Jarvis, M.C. 1992. Mannan of palm kernel. *Phytochemistry*, 31(2): 463–464.

Mohd. Sukri, I., Mohd. Ariff, O., Atil, O. & Ahmad Khusairi, D. 1999. The effects of oil palm by-products-based rations on growth, carcass characteristics and quality of beef cattle in feedlot. MARDI-PORIM Project Report. 10 p.

MPOA [Malaysian Palm Oil Association]. 2005. Cruel oil: How palm oil harms health, rainforest and wildlife. Special Report to the World Bank. MPOA, Kuala Lumpur, Malaysia.

MPOB [Malaysian Palm Oil Board]. 1992. Selected readings on palm oil and its uses. pp. 24–59, *in:* Abdulllah Ariffin *et al.* (editors). *Palm Oil Familiarization Programme.* PORIM, Bangi, Malaysia.

MPOB. 2009. Malaysian palm Oil – fact sheets. Malaysian Palm Oil Board. 63 p.

MPOPC [Malaysian Palm Oil Promotion Council]. 1995. Malaysian Palm Oil. 36 p.

Mustafa, M.F., Alimon, A.R., Ismail, I., Hair-Bejo, M. & Wan Zahari, M. 2001. Effect of palm kernel cake on performance and nutrient digestibility of Muscovy ducks. *Malaysian Journal of Animal Science,* 7(1): 63–68.

Ng, W.K. 2004. Researching the use of palm kernel cake in aquaculture feeds. Palm Oil Developments, 41, 19-21.

Ng, W.K. 2010. An overview of alternative and novel lipid sources for the global aquafeed industry. pp. 29–38, *in:* Proceedings of the 4th International Conference on Animal Nutrition, Johore Bahru, Malayia.

Ng, W.K. & Chen, M.L. 2002. Replacement of soybean meal with palm kernel meal in practical diets for hybrid Asian-African catfish, *Clarias macrocephalus* × *C. gariepinus. Journal of Applied Aquaculture,* 12: 67–76.

Ng, W.K., Lim, H.A., Lim S.L. & Ibrahim, C.O. 2002. Nutritive value of palm kernel meal pre-treated with enzyme or fermented with *Trichoderma koningii* (Oudermans) as a dietary ingredient for red hybrid tilapia (*Oreochromis* sp.). *Aquaculture Research,* 33: 1199–1207.

Ng, W.K., Wang, Y., Ketchimenin, P. & Yuen, K.H. 2004. Replacement of dietary fish oil with palm fatty acid distillate elevates tocopherol and tocotrienol concentrations and increases oxidative stability in the muscle of African catfish, *Clarias gariepinus*. *Aquaculture*, 233(1-4): 423–437.

Noraini, S., Wong, H.K., Sarah, R., Mohd. Fazli, F.A., Zainodin, H., Rosnizah, H. & Norham, I. 2008. Performance of broiler chickens fed fermented palm kernel expeller (PKE). pp. 159–162, *in:* Proceedings of the 3rd International Conference on Animal Nutrition, 29–31 July 2008, Hotel Equatorial, Bangi Selangor, Malaysia.

Oil World. 2009. Oil world statistics update. ISTA Mielke GmbH, Hamburg, Germany.

Ong, S.H. & Abu Hassan, O. 1991. Rapid, simple and economic methods for detection of persistent organochlorine insecticide residues in feeds and animal products. Recent innovations in the animal and animal products industry. pp. 20–23, *in:* Proceedings of the 14th Malaysian Society of Animal Production Annual Conference, 8–9 May 1991, Genting Highlands, Pahang, Malaysia.

Oshibe, A., Wan Zahari, M., Nor Ismail, M.S., Subramaniam, K. & Hayakawa, H. 2000. Effects of varying levels of oil palm fronds on intake and growth and performance of beef cattle. *In:* Proceedings of the 22nd Malaysian Society of Animal Production Annual Conference, 29 May–1 June 2000, Kota Kinabalu, Sabah, Malaysia.

Oshibe, A., Ukawa, H., Sarmin, S., Arbain, R., Yunus, I. & Mohd. Jaafar, D. 2001. Change in physical property of oil palm frond (OPF) and energy consumption during pellet processing. pp. 76–77, *in:* Proceedings of the 23rd Malaysian Society of Animal Production Annual Conference, 27–29 May 2001, Langkawi, Malaysia.

Oshio, S., Abu Hassan, O., Mohd. Jaafar, D. & Ismail, R. 1991. Processing of oil palm trunks for rumiant feed. *In:* Proceedings of the 3rd International Symposium on the Nutrition of Herbivores, 25–30 August 1991, Penang, Malaysia.

Playne, M.J. 1978. Differences between cattle and sheep in their digestion and relative intake of a mature tropical grass hay. *Animal Feed Science and Technology*, 3(1): 41–49.

Preston, T.R. & Leng, R.A. 1987. *Matching ruminant production systems with available resources in the tropics and sub-tropics.* Penambul Books, Armidale, Australia.

Radim, D., Alimon, A.R. & Yusnita, Y. 2000. The effect of replacing corn with rice bran and palm kernel cake in layer rations. pp. 177–178, *in:* Proceedings of the 22nd Malaysian Society of Animal Production Annual Conference, 29 May–1 June 2000, Kota Kinabalu, Sabah, Malaysia.

Reid, R.L., Jung, G.A., Cox-Ganser, J.M., Rybeck, B.F. & Townsend, E.C. 1990. Comparative utilization of warm and cool season forages by cattle, sheep and goats. J*ournal of Animal Science,* 68: 2986–2994.

Ramli, M.N., Suparjo, N.M., Nasyah Rita Azira, M.A.N., Siti Hajar, Z., Kamaluddin, H., Zainal Abidin, A.R. & Rashidah, A. 2010. pp. 357–360, *in:* [Proceedings of the] 4th International Conference on Animal Nutrition. 21–23 September 2010, Johore Bharu, Malaysia.

Saenphoom, P., Liang, J.B., Ho, Y.W., Loh, T.C. & Rosfarizan. 2010. Effect of enzyme treatment on nutritive value of palm kernel expeller cake. pp. 303–304, *in:* Proceedings of the 4th International Conference on Animal Nutrition, 21–23 September 2010, Johore Bharu, Malaysia.

Shamsudin, A.B., Mohd. Sukri, I. & Abdullah Sani, R. 1993. Feedlot performance of swamp buffalo fed with palm kernel cake- and sago meal-based ration. pp. 50–51, *in:* Proceedings of the 16th Malaysian Society of Animal Production Annual Conference, 8–9 June 1993, Langkawi, Malaysia.

Siew, W.L. 1989. Characteristics and uses of Malaysian palm kernel cake. *PORIM Technology*, No 14: 2–3.

Sukhija, P.S. & Palmquist, D.L. 1990. Dissociation of calcium soaps of long chain fatty acids in rumen fluid. *Journal of Dairy Science*, 73(7): 1784–1787.

Sukkasame, N. 2000. Effect of palm kernel cake levels on growth performance of the nile tilapia (*Oreochromis niloticus* Linn). *In:* Proceedings of the 26th Congress on Science and Technology of Thailand. 18-20 Oct 2000, Queen Sirikit National Convention Center, Bangkok, Thailand.

Tang, T.S. 2000. Composition and properties of palm oil products. pp. 845–891, *in: Advances in Oil Palm Research*. Vol. II. Malaysian Palm Oil Board.

Tung, C.M., Liang, J.B., Tan, S.L., Ong, H.K. & Jelan, Z.A. 2001. Effects of substituting grain concentrate with cassava fodder in oil palm frond-based diets for cattle. pp. 34–35, *in:* Proceedings of the 23rd Malaysian Society of Animal Production Annual Conference, 27–29 May 2001, Langkawi, Malaysia.

Van Horn, H.H., Marshall, S.P., Floyd, G.T., Olaloku, E.A., Wilcox, C.J. & Wing, J.M. 1980. Complete rations for growing dairy replacements utilizing by-product feedstuffs. *Journal of Dairy Science*, 63(9): 1465–1474.

Wan Zahari, M. & Alimon, A.R. 2003. Use of palm kernel cake in compound feed. Paper presented at the Fourth National Seminar for Popularization of Oilmeal Usage in Compound Cattle, Poultry and Aqua Feeds. Chandigarh, India, 16 January 2003.

Wan Zahari, M. & Alimon, A.R. 2004. Use of palm kernel cake and oil palm by-products in compound feed. *Palm Oil Developments*, 40: 5–9.

Wan Zahari, M., Mohd. Sukri, I. & Wong, H.K. 2004. Spent bleaching earth from the refining of crude palm oil. (i) The processing aspect and the nutritive value for livestock feeding. *In:* Proceedings of the 1st International Conference on Animal Nutrition (ICAN), Kuala Lumpur, Malaysia.

Wan Zahari, M., Wong, H.K. & Hussain, S.A.S. 2009. Utilization of animal feedstuffs in Malaysia. pp. 1–10, *In: Animal Feedstuffs in Malaysia – Issues, Strategies and Opportunities*. Academy of Sciences of Malaysia.

Wan Zahari, M., Mohd. Ariff, O., Mohd. Sukri, I., Oshibe, A. & Hayakawa, H. 2000. Oil palm by-products and urea molasses mineral blocks as feed resources for buffaloes in Malaysia. *In:* Proceedings of the 3rd Asian Buffalo Congress, Kandy, Sri Lanka.

Wan Zahari, M., Nor Ismail, M.S., Mohd. Sukri., I., Abu Bakar, C., Subramaniam, K., Rashidah, A. & Mohd. Yunus, I. 2002. Long-term feeding of complete feeds based on ground OPF in pellet or cube form to growing beef crossbred heifers. *In:* Proceedings of the 24th Malaysian Society of Animal Production Annual Conference, 19–23 May 2002, Penang, Malaysia.

Wan Zahari, M., Abu Hassan, O., Wong, H.K. & Liang, J.B. 2003. Utilization of oil palm frond-based diets for beef and dairy production in Malaysia. *Asian-Australian Journal of Animal Sciences,* 16(4): 625–634.

Wong, H.K. & Wan Zahari, M. 1992. Characterization of oil-palm by-products as feed for ruminants. pp. 58–61, *in:* Proceedings of the 15th Annual Conference of the Malaysian Society of Animal Production, Kuala Terengganu, Malaysia.

Wong, H.K. & Wan Zahari, M. 1997. Nutritive value of palm kernel cake and cocoa pod husks for growing cattle. *Journal of Tropical Agriculture and Food Science*, 25(1): 125–131.

Wong, H.K., Noraini, S., Mardhati, M. & Wan Zahari, M. 2009. New technologies in the utilization of palm kernel cake. *In: Feed Production and Processing Management*. Proceedings of the 5th Asian Livestock and Feed Industry Conference, 2009. 27–21 October 2009, Kuala Lumpur Convention Centre, Malaysia.

Yeong, S.W. 1983. Amino acid availability of palm kernel cake, palm oil sludge and sludge fermented product (Prolima) in studies with chickens. *MARDI Research Bulletin*, 11(1): 84–88.

Yeong, S.W. 1987. The use of palm oil by-product (POME) as feed for laying chickens in Malaysia. p. 211, *in:* Proceedings of the 4th AAAP Animal Science Congress, Hamilton, New Zealand, 1987.

Yeong, S.W., Mukherjee, T.K. & Hutagalung, R.I. 1981. The nutritive value of PKC as a feedstuffs for poultry. pp. 100–107, *in:* Proceedings of the National Workshop on Oil Palm By-Products Utilization, Kuala Lumpur, Malaysia.

Yeong, S.W., Syed Ali, A.B. & Faezah, M. 1980. The nutritive values of palm oil effluent product (Prolima) as a protein source in broiler diets. *MARDI Research Bulletin,* 8(2): 247–259.

Zin, Z.Z. 2000. Agronomic utilization of wastes and environmental management. pp. 1413–1438, *in: Advances in Oil Palm Research,* Vol. 2. Malaysian Palm Oil Board.

Chapter 14
Use of palm kernel cakes (*Elaeis guineensis* and *Orbignya phalerata*), co-products of the biofuel industry, in collared peccary (*Pecari tajacu*) feeds

Natália Inagaki de Albuquerque,[1] Diva Anélie de Araujo Guimarães,[2] Hilma Lúcia Tavares Dias,[2] Paulo César Teixeira[3,4] and José Aparecido Moreira[5]

[1] Embrapa Amazônia Oriental, Tv. Enéas Pinheiro s/n, Bairro Marco, CEP 66.095-100, Belém,Pará, Brazil

[2] Instituto de Ciências Biológicas, Universidade Federal do Pará, Rua Augusto Corrêa n° 1, Bairro Guamá, CEP 66075-110, Belém, Pará, Brazil

[3] Embrapa Amazônia Ocidental, Rodovia AM 010, km 29, Caixa Postal 319, CEP 69.011-970, Manaus, Amazonas, Brazil

[4] Embrapa Solos, Rua Jardim Botânico, 1024, Bairro Jardim Botânico, CEP 22460-000, Rio de Janeiro, Rio de Janeiro, Brazil.

[5] Universidade Federal do Rio Grande do Norte, Caixa Postal 1524 – Campus Universitário Lagoa Nova, CEP 59072-970, Natal, Rio Grande do Norte, Brazil

E-mail for correspondence: natalia@cpatu.embrapa.br

ABSTRACT

The oil palm (*Elaeis guineensis*) and the babassu (*Orbignya phalerata*) are palms of commercial interest in tropical countries and are found in the Brazilian Amazon. The oil from these palms has diverse uses, such as food, production of charcoal, soap and, most recently, biodiesel. The remainder of the plant, which is the bulk, is not normally commercialized, making it an ideal alternative source of low-cost energy for animal feed. The systems for breeding wild animals in captivity for commercialization and sustainability have an important role in conservation, because these species of game animals are under constant environmental pressure. For the collared peccary (*Pecari tajacu*) production system, the major part of the cost is feed. If alternative sources of low-cost animal feed could be used in the animal's diet, the production of the collared peccary could provide a new source of income for rural Brazilian producers. The use of co-products of oil palm and babassu has been found to be positive both for performance and for carcass characteristics of those animals bred in captivity. The replacement of 40 percent and 15 percent of the energy components of the traditional collared peccary diet with babassu and oil palm, respectively, showed the best improvement in the productive performance, demonstrating that they could reduce feeding costs while maintaining good animal development.

INTRODUCTION

Palms are plants typical to the tropics, and some are sufficiently prolific to be relevant to the subsistence of indigenous and traditional peoples (Clement, Lleras Peres and Van Leeuwen, 2005), providing an important contribution to the economies of several tropical countries (Lopes *et al*., 2008). The oil palm and babassu are examples of species of commercial interest.

In recent years, production of the oil palm has expanded greatly on a large scale in many tropical countries (e.g. Brazil, Colombia, Ecuador, Indonesia, Malaysia and Thailand). The oil palm belongs to the monocotyledonous class, order Palmales, family Arecaceae and genus *Elaeis*. There are two species of commercial interest: *E. guineensis* Jacq, of African origin, known as oil palm, and *E. oleifera* Cortés, known as American oil palm or Caiaué. The palm of African origin is the principal species planted commercially, using varieties of the Tenera type. The American species is used in improvement programmes to obtain interspecific hybrids (*E. oleifera* × *E. guineensis*) especially for plantations in regions subject to fatal yellowing disorder. The ideal climatic conditions for its cultivation are: annual rainfall of more than 2000 mm that is well distributed, without a defined dry season, and a minimum of 100 mm per month; an average maximum temperature between 29 and 33 °C, with a minimum temperature between 22 and 24 °C; a daily insolation period of between 5 and 7 hours, and daily radiation of 15 MJ/m^2 (Corley and Tinker, 2003).

The oil palm, a perennial plant with continuous production throughout the year, has an economically productive life of around 25 years. This species is the most productive oleaginous palm and can produce from 6 to 10 tonne of oil per hectare per year. The oil palm produces at least 3 to 8 times more oil than most other oleaginous seeds. The oil

MAIN MESSAGES

- **Babassu cake substitution for maize as an energy source up to a level of 40 percent improved productive performance of collared peccaries, and good results were obtained with respect to dressing percentage of collared peccaries slaughtered at the terminal phase.**
- **Oil-palm cake can be used to replace 15 percent of the energy components of the traditional collared peccaries diets at the terminal phase.**
- **Babassu and oil-palm cakes could reduce feeding costs while maintaining good animal development.**

palm produces its fruit in clusters, varying in size from 10 to 40 kg per cluster. The individual fruit consists of an exterior layer (exocarp), pulp (mesocarp), endocarp and seed. The primary products produced from the fruit of the oil palm are oil and cake. The palm oil is extracted from the pulp of the fruit (mesocarp), and the palm kernel oil from the seed (endosperm). The ratio between the quantities produced by these types of oils is approximately 9:1 (palm oil:palm kernel oil). The cake results from the process of extracting oil from the seed and contains 17–19 percent protein and acceptable bromatological characteristics, particularly in ruminant diets due to its high proportion of fibre, and is rich in arginine and glutamic acid. The average composition of palm kernel cake is 48 percent carbohydrate, 19 percent protein, 13 percent fibre, 5 percent palm kernel oil, 11 percent water and 4 percent ash (Hartley, 1988). Oil palm oil production exceeds 35 million tonne per year, with marked growth in the last two decades, and has become the most produced and commercialized vegetable oil in the world (USDA, 2006; FEDEPALMA, no date; Oil World, 2008).

Biofuel demand might greatly exceed that for edible use, and the interchangeability of the major oils, for edible and biofuel uses, means that this demand will drive oil palm expansion, whether or not palm oil is actually used for biodiesel (Corley, 2009).

Although the oil palm plantations are, in some situations, world-challenged by presenting some environmental risks (e.g. Friends of the Earth, 2005; Rosenthal, 2007; Fitzherbert *et al.,* 2008; Koh and Wilcove, 2008; Butler and Laurence, 2009), these risks can be considerably reduced through sustainable development practices, with proper management (Basiron, 2007; Corley, 2009; Boyfield, 2010; Nelson *et al.,* 2010).

The palm oil industry could supply sufficient vegetable oil to meet the growing food requirements for the global population in 2050, and there is sufficient land available for necessary expansion without the need for deforestation (Corley, 2009). Due to the fact that Malaysia does not have physical space to increase its plantation area (Thoenes, 2006), it is necessary to increase cultivation of oil palm elsewhere. Various countries could emerge as major producers of palm oil (East and West Africa, other Asian countries, and Central and South America). Brazil, in spite of currently having little market penetration in terms of global production of palm oil, has a great potential for expansion and has recently expanded production in this sector. To control expansion of oil palm plantations in the Brazilian Amazon and minimize possible negative environmental impacts, the Brazilian government has requested the implementation of agri-ecological zoning for the culture. This zoning is a technico-scientific basis for achieving sustainability by defining lands suitable for oil palm culture (Ramalho Filho and Motta, 2010). The focus area, set in the Amazonian biome (5 million km^2), refers to areas already deforested, with the exception of strictly protected areas (state and national parks, and indigenous reserves). The areas already deforested and considered suitable for the cultivation of oil palm total 30 million ha (300 000 km^2), being some 5.9 percent of the Brazilian legally-defined Amazon (Ramalho Filho *et al.*, 2010).

The babassu (*Orbignya phalerata* Mart.) is a palmaceous plant of the Arecaceae family, found in abundance in the Brazilian Amazon region, especially in the States of Maranhão, Tocantins, Pará and Piauí, and possesses a high energy potential. Maranhão State has around 65 percent of the national occurrence of the palm, which represents 30 percent of the State surface (Ferreira, 1999). Babassu is a native of the transition zone between the savannah and open forests of the southern Amazon, and is in areas anthopogenically altered (Clement, Lleras Peres and Van Leeuwen, 2005), often appearing in spontaneous homogeneous groupings. This species covers extensive regions in Brazil, Bolivia and Suriname (Zylbersztajn *et al.,* 2000).

The babassu produces drupe type fruits with oleaginous and edible seeds from which the oil is extracted in sufficient quantities for local needs. Fundamental aspects for the exploitation of the babassu are the harvesting and the gathering system. There are no commercial plantations of these palms in the world, and the fruits are collected from natural forests by native populations. It is a natural resource whose economic importance has been recognized. Its exploitation is characterized by the collection of fruits from natural stands of native vegetation with no additional management action.

Natural babassu density in the forest varies from 1 to 4000 plants per hectare, with an average of 1111 plants per hectare (Ferreira, 1999), but not all these plants can be utilized. Each adult plant produces approximately

2000 fruits per year (Lorenzi *et al.*, 1996). Each fruit can weigh between 40 and 400 g dry weight (Revilla, 2002). Each 17.6 kg of fruit provides 2.6 kg of epicarp, 3.5 kg of mesocarp, 10.4 kg of endocarp and 1.1 kg of kernels (Wisniewski and Melo, 1981).

The seed is the principal product extracted from the fruit, and represents the greatest commercial and industrial value. One fruit contains from 3 to 5 seeds, which are extracted manually by traditional cottier families, being the most important source of income for the landless population in the interior regions where babassu is found. In the state of Maranhão, seed extraction involves more than 300 000 families, especially women (called "breakers").

The food products from the babassu and oil palm production could significantly contribute to food security in the Amazon forest region, and currently provide a large variety of foods and an adequate health standard for the population (Alencar *et al.,* 2007). These palms could be used for numerous purposes, such as the production of starch, charcoal, soap, margarine, oil tar, alcohol, palmetto and, more recently, biodiesel. Nevertheless, the remainder of the plant, which constitutes the bulk of the plant, is not normally commercialized, and could be considered as an alternative source of low-cost energy for animal feed.

USE OF BABASSU (*ORBIGNYA PHALERATA*) IN THE FEED OF COLLARED PECCARIES RAISED IN CAPTIVITY

Very few studies have been carried out regarding sustainable production systems for native wild animals maintained in captivity for commercial purposes. These systems may play an important role in conservation because these species are under constant human pressure due to subsistence and commercial hunting, fragmentation of the habitat and deforestation.

In the Amazon region, subsistence hunting of game animals provides a significant proportion of the protein component of the diet of rural families (Robinson and Bodmer, 1999; Peres, 2000, 2001). In certain regions, the trade in bushmeat and other co-products of game animals is a great source of income (Bodmer, 2000; Baia Junior, Guimarães and Le Pendu, 2010.).

The collared peccary (*Pecari tajacu*) is a wild species which is frequently hunted. Its diet in its natural environment is basically fruit, leaves and roots, and in captivity can easily adapt to different types of feed, including grain, fruits, potherbs, roots and fodder, and accepts porcine commercial feed (Albuquerque and Hühn, 2001; Albuquerque *et al.*, 2004)

The collared peccary belongs to the Suiformes suborder and the Tayassuidae family. The animals belonging to his family possess a stomach subdivided into compartments, and some authors suggest that its digestive physiology could be similar to that of ruminants. Due to its low requirements for protein and its high digestive performance, these animals are able to adapt to green foods such as fodder (Comizzoli *et al.*, 1997; Cavalcante Filho *et al.*, 1998; Mendes, 2008), and the wild collared peccary resort to this type of diet when there is a scarcity of fruits.

Captive breeding of collared peccary has been proposed by Nogueira-Filho (1999), Albuquerque *et al*. (2004) and Garcia *et al*. (2005). This could be a new source of income for rural Brazilian producers, supported by supplementing the animal's diet with alternative sources of low-cost feed.

Albuquerque (2006) studied the use of babassu cake as an alternative energy source in the captive collared peccary's diet. In the experiment, babassu cake substituted maize at varying levels in feed formulated for animals in the termination phase, and animal performance was evaluated using daily weight gain and daily feed consumption. After the experimental phase the animals were slaughtered to analyse the carcasses.

Table 1 shows the chemical characteristics of the experimental feed, and Table 2 shows the average composition of the ingredients used in the experiment. The experimental feed was based on maize and soy bran, replaced with varying levels of babassu cake.

At the end of the experimental phase, when the experimental animals reached slaughter weight (average of 16.25 kg and 7 months old), they were weighed. After this, the animals were fasted for 24 hours, re-weighed and

TABLE 1
Average chemical characteristics of the ingredients of the experimental feed

Ingredient	DM	MM	P	CF	CP	Ca	EE	NDF	ADF	Sodium
Soy bran(1)	88.1	6.6	0.6	5.9	45.5	0.3	1.4	14.1	7.8	0.1
Maize(1)	87.1	1.3	0.2	2.0	8.6	<0.1	3.5	11.4	3.4	<0.1
Babassu (cake)(2)	90.2	4.6	0.7	26.0	17.3	0.1	3.1	–	–	–
Soy oil	99.3	–	–	–	–	–	99.0	–	–	–
Dicalcium phosphate	–	–	18.5	–	–	24.8	–	–	–	–
Calcitic lime	–	–	<0.1	–	–	31.9	–	–	–	–
Salt	–	–	–	–	–	–	–	–	–	39.7
Lysine-HCl	–	–	–	–	79.1	–	–	–	–	–

Notes: DM = dry matter; MM = mineral material; P = phosphorus; CF = crude fibre; CP = crude protein, Ca = Calcium; EE = ether extract; NDF = neutral-detergent fibre; ADF = acid-detergent fibre.
Sources: (1) Rostagno *et al*., 2000. (2) Embrapa, 1991.

TABLE 2
Average composition of experimental feeds

Ingredient	Inclusion levels of babassu cake in the feed			
	TA	TB	TC	TD
Babassu (cake)	0.0	15.7	31.3	47.0
Maize	78.3	62.7	47.0	31.3
Soy bran	14.6	14.6	14.6	14.6
Soy oil	1.0	3.5	3.5	3.5
Dicalcium phosphate	1.25	1.25	1.25	1.25
Calcitic lime	0.78	0.78	0.78	0.78
Salt	0.40	0.40	0.40	0.40
Lysine-HCl	0.15	0.00	0.00	0.00
Vitamin supplement(1)	0.40	0.40	0.40	0.40
Mineral supplement(2)	0.10	0.10	0.10	0.10
Inert	3.00	0.65	0.65	0.65
Total	100.00	100.00	100.00	100.00
Calculated Values				
Digestible energy (Kcal)	3304	3304	3304	3304
Gross protein	13.5	13.5	13.5	13.5
Calcium	1.19	1.19	1.19	1.19
Total phosphorus	0.78	0.78	0.78	0.78
Available phosphorus	0.53	0.53	0.53	0.53
Lysine	0.49	0.49	0.49	0.49
Methionine+cystine	0.41	0.41	0.41	0.41
Threonine	0.41	0.41	0.41	0.41
Tryptophan	0.11	0.11	0.11	0.11
Sodium	0.19	0.19	0.19	0.19

Notes: TA = Control feed based on maize and soy bran; TB = Feed containing 20% babassu cake and 80% maize; TC = Feed containing 40% babassu cake and 60% maize; TD= Feed containing 60% babassu cake and 40% maize.
(1) Vitamin supplementation per kg of feed: vitamin A = 625 000 IU; vitamin D3 = 125 000 IU; vitamin E = 3375 IU; folic acid + 875 mg; biotin = 27.56 mg; choline chloride = 2475 mg; niacin = 4000 mg; pantothenic acid = 2000 mg; thiamine = 175 mg; riboflavin = 550 mg; pyridoxine = 175 mg; vitamin B_{12} = 2800 mg; antioxidant = 200 mg.
(2) Mineral supplementation per kg of feed: Iron = 22 000 mg; copper = 5000 mg; zinc = 18 750 mg; manganese = 12 500 mg; iodine = 238 mg; selenium = 56.3 mg; cobalt = 116 mg.
Values calculated in accordance with the nutritional demands in basal feed for swine of low genetic potential.
Source: Rostagno *et al.,* 2000.

TABLE 3
Average daily weight gain (DWG) and daily feed intake (DFI) of the collared peccary in the terminal phase

Parameter	Inclusion levels of babassu cake in the feed (%)				
	0	20	40	60	SE
DWG (g)	32.7	38.0	44.7	37.0	4.6
DFI (g)	355.5	359.1	356.1	362.2	11.4

Notes: SE = Standard error. *Source*: Albuquerque, 2006.

then sent to the abattoir. The characteristics of the animal carcasses included in this study were dressing percentage, corporal composition, carcass measurements, organs and glands, and commercial cuts. Table 3 shows the daily weight gain and daily feed intake in the terminal phase.

In this experiment, no significant (P >0.05) relationships were observed between the levels of babassu cake and DWG and DFI. The DWG at the 40 percent babassu cake inclusion level showed an increase of 36.74 percent compared with the basal diet. No significant effects were observed in DFI.

Evaluation of the carcass

Tables 4, 5, 6 and 7 show the variables studied in the carcass evaluation of the experimental collared peccaries. The levels of babassu cake did not affect the variables of live weight, fasting weight, hot carcass, cold carcass, length, hide, hind and front feet, as shown in Table 4.

Albuquerque (1993) evaluated the carcasses of male, female and castrated male capybaras (*Hydrochoerus hydrochaeris*) slaughtered after the terminal phase, and found no significant differences (P >0.05) in carcass components among different experimental groups.

Silva *et al.* (2002) studied the effects on the animal carcass of different levels of CP in the diet of collared peccaries slaughtered after the terminal phase, but they found no significant differences. The carcass length was between 55.25 and 57.63 cm, and was greater than reported by Albuquerque (2006). The authors did not report the age of the animals studied, but it is thought that they were older, due to the differences in body length.

Albuquerque (2006) observed no significant differences (P >0.05) in hot or cold dressing percentages related to varying levels of babassu cake (Table 5), and ribs, gammon, shoulder blades and percentage of gammon in relation to the cold, left half-carcass (Table 6). There was an increase over basal feed of 7.1 percent for ribs, 8.9 percent for gammon, 6.4 percent for shoulder blades, and 21.6 percent for percentage of gammon relative to the cold, left half-

TABLE 4
Measurements of the carcass components of slaughtered collared peccaries after the terminal phase

Parameter	Levels of babassu cake in the feed (%)				
	0	20	40	60	SE
Live weight (g)	16533	15633	16600	16233	834.8
Fasting weight (g)	16467	15700	16400	16000	746.8
Hot carcass (g)	9233	8267	9500	9500	407.5
Cold carcass (g)	9141	8184	9405	9405	403.4
Carcass length (cm)	23	21	21	21	0.8
Blood (g)	148	212	217	204	27.0
Hide (g)	2088	1892	1998	1980	103.5
Hind feet (g)	123	122	130	117	4.7
Front feet (g)	122	122	120	120	2.7

Notes: SE = Standard error. *Source*: Albuquerque, 2006.

TABLE 5
Averages of the dressing percentage of slaughtered collared peccaries after the termination phase

Parameter	Levels of babassu cake in the feed (%)				
	0	20	40	60	SE
HDP (%)	56.1	53.2	57.8	59.4	2.62
CDP (%)	55.5	52.6	57.2	58.8	2.59

Notes: SE = Standard error; HDP = Hot dressing percentage; CDP = Cold dressing percentage. *Source*: Albuquerque, 2006

TABLE 6
Average features of the commercial cuts removed from the cold, left half-carcass of the collared peccaries slaughtered after the termination phase

Parameter	Levels of babassu cake in the feed (%)				
	0	20	40	60	SE
Ribs (g)	1320	1147	1147	1413	186.6
Gammon (g)	1428	1420	1468	1555	80.2
Shoulder blade (g)	967	953	943	1028	67.7
% Gammon(1)	30.6	32.4	35.3	37.2	3.4

Notes: SE = Standard error. (1) % of gammon in relation to the left side cold half carcass. *Source*: Albuquerque, 2006.

TABLE 7
Average percentages of organs and glands in relation to the carcass of the collared peccaries slaughtered after the terminal phase

Parameter	Inclusion levels of babassu cake in the feed (%)				
	0	20	40	60	SE
Stomach (%)	5.0	4.7	5.2	4.0	0.65
Heart (%)	0.7	0.8	0.7	0.6	0.08
Lung (%)	1.3	1.8	1.5	1.2	0.11
Liver (%)	2.1	2.7	2.5	2.2	0.19
Spleen (%)	1.1	0.8	0.7	0.5	0.24
Kidneys (%)	0.5	0.6	0.6	0.6	0.07
Intestines (%)	5.9	8.2	7.3	6.5	0.93
Total (%)	16.6	19.7	18.3	15.3	1.73

Notes: SE = Standard error. *Source*: Albuquerque, 2006.

carcass. In the diet with an inclusion level of 40 percent babassu cake, the increase was 2.8 percent for gammon and 15.4 percent for percentage of gammon in relation to the cold, left half-carcass.

Silva *et al*. (2002) studied the effect of different inclusion levels of CP in the feed on carcass and meat of collared peccaries slaughtered after the terminal phase, and found no significant differences (P >0.05) for the carcass parameters studied. Similar to observations of Albuquerque (2006), the average dressing percentage was between 56.88 and 59.47 percent. The percentage of gammon in relation to the carcass was between 35.0 and 38.2 percent, showing slightly higher values than reported in Albuquerque (2006).

Some bovine data for dressing percentage were poorer when compared with that of collared peccaries reported by Albuquerque (2006), such as the data found by Schwarz *et al.* (1993), who found average dressing percentages of between 57.7 and 58.4 percent, and Holzer *et al.*, (1999), who reported an average dressing percentage between 55.4 and 57.4 percent. The inclusion of different levels of babassu cake showed no significant differences (P >0.05) in the values for organs and glands (Table 7).

Meat properties and fatty acids profile in the collared peccary gammon

Albuquerque *et al.* (2009) studied the organoleptic properties (cooking losses, shearing force, pH and water holding capacity) of gammon from 12 collared peccaries, and the fatty acid (FA) profile of the oil extracted from the meat. No significant differences (P >0.05) were observed in meat properties, and unsaturated FA (mono- and poly-unsaturates) were more frequent than saturated fatty acids in the collared peccary gammon meat. When comparing the meat from collared peccaries, bovines, ovines and swine, the collared peccary had more unsaturated FA (mono- and polyunsaturates) than saturated FA. The FA polyunsaturates are responsible for a reduction in cholesterol blood levels (Monteiro, Mondini and Costa, 2000), suggesting that the meat from the collared peccary is a healthy source of animal protein (Albuquerque *et al.*, 2009).

PALM KERNEL CAKE (*ELAEIS GUINEENSIS*) USE IN THE FEED OF COLLARED PECCARIES RAISED IN CAPTIVITY

The use of oil palm cake in the diet has been studied in various animal species: fish – *Pieractus mesopotamicus* and *Oreochromis niloticus* (Oliveira *et al.*, 1997, 2008; Pascoal, Miranda and Silva-Filho, 2006.); chicken (Onwudike, 1986, 1988; Farias-Filho *et al.,* 2006); and in swine (Rhule, 1996; Gómez, Benavides and Diaz, 2007.).

Embrapa Amazônia Oriental, in partnership with the Universidade Federal do Pará, embarked on a research project (PROFAMA, 2008) that evaluated the performance of collared peccaries bred in captivity on diets of oil palm kernel cake as an alternative feed source. Animal performances (daily weight gain and daily feed intake), the characteristics of the carcass and the non-carcass components were observed, and the bacterial microbiota in the gastro-intestinal tract of these animals was studied.

Forty male animals were used, aged between 8 and 10 months, in their final growth phase and weighing an average of 13.20 kg. During the experiment, the animals received varying levels of oil palm cake (T1 = 0% cake; T2 = 7.5% cake; T3 = 15% cake; and T4 = 22.5% cake). The proximate analysis of the feed is shown in Table 8, and the nutritional analysis in Table 9.

At the end of each experimental phase, the animals were slaughtered to evaluate the effects of the feed utilized on the carcass and non-carcass characteristics (gammon and carcass dressing percentage, head, hide, blood, feet, carcass length, organs and glands, and commercial cuts) and live weight and fasting weight.

The results observed in the feed with the inclusion of oil palm cake demonstrated that its use in the diet of the collared peccary in an intensive breeding system could be a regional low-cost nutritional component.

Rhule (1996) studied the effect of breed on the growth of swine with varying levels of oil palm cake in the feed, and observed more weight gain in swine than in collared

TABLE 8
Chemical characteristics (percentage basis) of the experimental feed

Ingredient	DM	MM	P	CF	CP	Ca	EE	NDF	ADF	Na
Soy bran(1)	88.1	6.6	0.6	5.92	45.54	0.3	1.4	14.1	7.8	0.1
Maize(1)	87.1	1.3	0.2	1.95	8.57	<0.1	3.5	11.4	3.4	<0.1
Oil palm (cake)(2)	94.9	3.1	–	–	15.70	–	–	83.2	80.3	–
Wheat bran(3)	88.0	5.6	1	9.52	50.63	0.2	3.5	44.3	13.5	<0.1
Meat/bone flour(3)	93.4	25.0	5.0	1.61	59.9	8.6	12.4	–	–	–
Dicalcium phosphate	–	–	18.5	–	–	24.8	–	–	–	–
Calcitic lime	–	–	<0.1	–	–	31.7	–	–	–	–
Salt	–	–	–	–	–	–	–	–	–	39.7

Notes: DM = dry matter; MM = mineral material; P = phosphorus; CF = crude fibre; CP = crude protein, Ca = Calcium; EE = ether extract; NDF = neutral-detergent fibre; ADF = acid-detergent fibre; Na = sodium.
Sources: (1) Rostagno *et al*., 2000. (2) Unpublished data from Animal Nutrition Laboratory, CENA-USP. (3) Valdares Filho *et al*., 2006.

TABLE 9
Composition of experimental feeds (on a percentage basis)

Ingredient	Oil palm cake inclusion level			
	0% (control)	7.5%	15%	22.5%
Maize grain	60.2	60.2	60.2	60.2
Palm oil cake	0.0	7.5	15.0	22.5
Wheat bran	31.0	23.5	16.0	8.5
Soy bran 45%	2.5	2.5	2.5	2.5
Meat and bone flour 55%	5.0	5.0	5.0	5.0
Lime	0.5	0.5	0.5	0.5
Vitamin supplement	0.4	0.4	0.4	0.4
Common salt	0.3	0.3	0.3	0.3
Mineral supplement	0.1	0.1	0.1	0.1
Total	100	100	100	100
Calculated values				
SDE (Mcal/kg)	3.05	3.06	3.07	3.07
Crude protein (%)	14.2	14.1	14.0	13.8
NDF (%)	5.7	10.9	16.1	21.3
ADF (%)	19.8	23.0	26.2	29.4
Ca (%)	0.68	0.67	0.66	0.65
Na (%)	0.18	0.18	0.18	0.18
Available P (%)	0.35	0.33	0.31	0.29
Total P (%)	0.66	0.59	0.52	0.45
Total lysine (%)	0.55	0.51	0.46	0.41
Total Methionine+cystine (%)	0.48	0.44	0.40	0.36
Total methionine (%)	0.22	0.21	0.19	0.17
Total threonine (%)	0.48	0.44	0.41	0.37
Total tryptophan (%)	0.13	0.11	0.10	0.08
Fat (%)	3.68	3.43	3.186	2.92

Notes: Values are calculated in accordance with the nutritional demands in basal feed for swine of low genetic potential (Rostagno *et al*., 2000). SDE = Swine Digestible Energy; NDF = neutral-detergent fibre; ADF = acid-detergent fibre; Ca = calcium; Na = sodium. Vitamin supplementation was (per kg of feed): vitamin A = 625 000 IU; vitamin D_3 = 125 000 IU; vitamin E = 3375 IU; folic acid = 875 mg; biotin = 27.56 mg; choline chloride = 2475 mg; niacin = 4000 mg; pantothenic acid = 2000 mg; thiamine = 175 mg; riboflavin = 550 mg; pyridoxine = 175 mg; vitamin B_{12} = 2800 mg; antioxidant = 200 mg. Mineral supplementation was (per kg of feed): Iron = 22 000 mg; copper = 5000 mg; zinc = 18 750 mg; manganese = 12 500 mg; iodine = 238 mg; selenium = 56.3 mg and cobalt = 116 mg.
Source: Rostagno *et al*., 2000.

peccaries. The differences observed in the weight gain between the collared peccary and the swine may be related to the physiological metabolism of each species, and genetic improvements.

TABLE 10
Daily weight gain (DWG) and daily feed intake (DFI) of collared peccaries fed with varying inclusion levels of oil palm cake

	Oil palm cake inclusion level			
	0%	7.5%	15%	22%
DWG (g)	38	54	70	28
DFI (g)	452	429	425	455

Source: Projeto PROFAMA 109/2008 FAPESPA/SEDECT/UFPA/Embrapa.

TABLE 11
Characteristics of the carcass and non-carcass components of collared peccaries fed with varying levels of oil palm cake

Parameter	Oil palm cake inclusion percentage			
	0%	7.5%	15%	22.5%
Live weight (kg)	15.05	14.25	16.00	15.3
Fasting weight (kg)	14.45	12.75	15.00	14.65
Dressing percentage (%)	58.4	58.4	56.8	60.4
Gammon dressing percentage (%)	29.7	32.1	31.2	29.8
Carcass length (cm)	56.3	57.0	57.5	61.8
Head (kg)	1.37	1.24	1.45	1.35
Hide (kg)	1.79	1.55	1.83	1.73
Organs and glands (kg)	1.65	1.43	1.36	1.35
Front and hind feet (g)	141	134	138	168
Blood (g)	197	206	205	200
Gammon (kg)	1.35	1.37	1.32	1.46
Ribs (kg)	1.17	1.12	1.34	1.31
Shoulder blade (g)	740	692	813	832

Source: Projeto PROFAMA 109/2008 FAPESPA/SEDECT/UFPA/Embrapa.

The characteristics of the carcass and of the non-carcass components in collared peccaries fed with varying levels of oil palm cake are shown in Table 11. Dressing percentage variations from 56.8 to 60.4 percent were observed. These values are close to those of Silva *et al.* (2002), who observed dressing percentages from 56.9 percent to 59.5 percent when evaluating different levels of diet crude protein, and slightly higher than those reported by Albuquerque (2006), who tested increasing levels of babassu cake (20, 40 and 60 percent) giving dressing percentages of 53.2, 57.8 and 59.4 percent, respectively.

In the captive white-lipped peccary fed with fodder and feed (13 percent of crude protein and 2800 kcal/kg), the average dressing value was 53.8 percent, slightly below that observed in collared peccaries (Ramos *et al.,* 2009), probably related to the different nutritional composition in the diet offered. This fact can be verified in domesticated swine breeds fed with different diets containing oil palm cake and which present distinct dressing percentages (Rhule, 1996; Gómez, Benavides, Diaz, 2007; Oluwafemi and Akpodiete, 2010).

In javelinas (*Sus scrofa*) fed with sugar cane, vegetables and commercial swine feed, dressing percentages were observed similar to those of domestic swine fed with diets containing oil palm cake (Marchiori, 2001), suggesting that this diet supports good animal performance.

The dressing percentages of collared peccaries are similar or better than other free-ranging artiodactyl wild animals, such as: *Lama glama* (Pérez *et al.*, 2000), *Lama guanicoe* (Gonzalez *et al.*, 2004), *Aepyceros melampus* (Hoffman, 2000), *Tragelaphus strepsiceros* (Hoffman *et al.,* 2009), and *Damaliscus dorcas philipsi* (Hoffman, Smith and Muller, 2008).

The gammon dressing percentage (29.7 to 32.1 percent) observed in the collared peccary (Table 11) was close to the values observed by Silva *et al.* (2002) (36.1 percent) and Albuquerque (2006) in the same species. These observations suggest that the inclusion of oil palm cake in the diet does not appear to prejudice collared peccary performance.

The weight of the shoulder blade was similar to that encountered by Albuquerque (2006) feeding varying levels of babassu cake in the diet of the collared peccary (953.3 g with 20 percent; 943.3 g with 40 percent; and 1028.3 g with a level less than 60 percent). These results were higher than those in the capybara, which did not exceed 800 g (Albuquerque, 1993).

The weight of the ribs was lower than that observed by Albuquerque in the same species and similar to those observed in capybara (Albuquerque, 1993).

Study of the bacterial microbiota from the gastro-intestinal tract

The project PROFAMA (2008) evaluated the bacterial population in the gastro-intestinal tract of collared peccaries and studied the adaptation of the bacterial populations with respect to different feed treatments. Microbiological evaluations were carried out on different components of the gastro-intestinal tract of 26 slaughtered collared peccaries.

In the 27 bacterial microbiota isolated, only Gram-negative bacteria were observed, including *Escherichia coli* (85.2 percent), *Shigella* spp. (7.4 percent), *Salmonella* spp. (3.7 percent) and *Klebsiella oxytoca* (3.7 percent). These results are similar to those reported in literature based on isolations of faecal micro-organisms from both domestic and wild animals (Adesiyun *et al.,* 1998; Melville *et al.,* 2004; Marinho, Meireles and Souza, 2004; Oliveira *et al.*, 2009).

TABLE 12
Gram-positive and Gram-negative bacteria (percentage) isolated post-slaughter from the gastro-intestinal tract of 26 collared peccaries

Bacterial species	Pre-stomach	Stomach	Intestine
Corynebacterium spp.	10	6.2	9.0
Escherichia coli	40	71.4	58.8
Klebsiella oxytoca	20	9.5	11
Klebsiella pneumoniae	10	0	0
Micrococcus spp.	90	56.2	63.6
Salmonella spp.	10	4.7	5.8
Serratia spp.	0	0	11.7
Shigella spp.	10	0	0
Staphylococcus spp.	0	25	18.8
Streptococcus spp.	0	12.5	9.0
Yersinia enterocolitica	10	14.2	11.7

Source: Projeto PROFAMA 109/2008 FAPESPA/SEDECT/UFPA/Embrapa

Eighty-five isolated bacterial microbiota were obtained, including 20 samples (23.5 percent) from the pre-stomach, 37 samples (43.5 percent) from the stomach, and 28 samples (32.9 percent) from the intestine.

Some of the genera and bacterial species identified are similar to those reported in swine (Jensen, 2001). Of these, *Lactobacillus* spp., *Streptococcus* spp., *Clostridium* spp., *Eubacterium* spp., *Fusobacterium* spp., *Bacterioides* spp. and *Peptostreptococcus* spp. are those most frequently isolated.

Some bacteria, namely *Clostridium perfringens*, *Salmonella* spp., *E. coli*, *Klebsiella* spp., *Campylobacter* spp. and *Pseudomonas aeruginosa* are etiologic agents responsible for enteritis in various animal species, including humans. Despite finding these highly pathogenic micro-organisms, the experimental animals did not present symptoms suggestive of gastro-enteritis.

Irrespective of the treatments the animals received, the results demonstrate that this does not affect the presence or frequency of the bacteria isolated from the gastro-intestinal tract of the collared peccary in captivity, with the majority of isolations having *E. coli* as part of the normal microbiota. It has become necessary to institute strict feed handling procedures to maintain the integrity of the gastrointestinal system in order to prevent diseases and to reinforce food safety measures.

KNOWLEDGE GAPS AND FUTURE RESEARCH NEEDS

In addition to the collared peccary, it is important to develop further studies on the captive management of other non-domestic neo-tropical animals of commercial interest, such as white-lipped peccary (*Tayassu pecari*), capybaras

(*Hydrochoerus hydrochaeris*), paca (*Cuniculus paca*), agouti (*Dasyprocta* spp.), broad-snouted caiman (*Cayman latirostris*), yacare caiman (*Caiman yacare*) and greater rhea (*Rhea americana*).

In order to make intensive neo-tropical animal production systems viable for those wild species that may be of economic importance, and for their sustainability and conservation, it will be necessary to study alternative feed resources, such as those already studied with the domestic species. This should be done with feed resources deriving from the agro-processing co-products of cassava, fruits and oil palms. To this could be added sugar cane forage, as suggested by Archimede and Garcia (2010), as this could provide a sustainable feed supply.

CONCLUSIONS

- Babassu cake substitution for maize as an energy source up to a level of 40 percent was a success in feed for collared peccaries in the terminal phase.
- Babassu cake, used to replace up to 40 percent of maize, obtained good results with respect to dressing percentage and commercial cuts of collared peccaries slaughtered at the terminal phase.
- Oil palm cake can be used to replace wheat bran as an energy source in feed for collared peccaries at the terminal phase.
- Oil palm cake used to replace wheat bran gave satisfactory results with respect to dressing percentage and commercial cuts of collared peccaries slaughtered at the terminal phase.

ACKNOWLEDGEMENTS

The research reported here was supported by FAPESPA (PROFAMA project 109/2008 FAPESPA/SEDECT/UFPA/Embrapa), Embrapa Amazônia Oriental and Universidade Federal do Pará. We are also grateful to ESALQ/USP and CENA/USP for the contributions to the research by Dr Carmen Contreras and Dr Cyro Meirelles, and to all the graduate and post-graduate students and technicians that helped in the research in various ways (Priscila Kahwage MSc, Jociel Costa MSc, Jurupytan Silva MSc, Hilma, Israel, Alice, Roberto, Hugo) and Mr Deoclécio Oliveira.

BIBLIOGRAPHY

Adesiyun, A.A., Seepesadsingh, N., Inder, L. & Caeser, K. 1998. Some bacterial enteropathogens in wildlife and racing pigeons from Trinidad. *Journal of Wildlife Diseases*, 34(1): 73–80.

Albuquerque, N.I. 1993. Ganho de peso na fase final de crescimento e sistematizaçao da avaliação de carcaça de três categorias de capivaras (*Hydrochoerus hydrochaeris hydrochaeris* L. 1766): machos inteiros, machos castrados e fêmeas. MSc Thesis. Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo, Piracicaba, Brazil. 65 p.

Albuquerque, N.I. 2006. Emprego do babaçu (*Orbignya phalerata*) como fonte energética para catetos (*Tayassu tajacu*). PhD Thesis. Universidade de São Paulo/USP, Piracicaba, São Paulo, Brazil. 79 p.

Albuquerque, N.I. & Hühn, S. 2001. Avaliação físico-química de espécies vegetais utilizadas na alimentação do caititu. *Boletim de Pesquisa. Embrapa Amazônia Oriental,* 36: 1–17.

Albuquerque, N.I. Guimaraes, D.A., Le Pendu, Y. & Silva, J.V. 2004. Criação intensiva de caititus (*Tayassu tajacu*): Experiência na Amazônia Brasileira. pp. 21–22, *in:* 6th Congreso Internacional Sobre Manejo De Fauna Silvestre Em La Amazônia Y Latinoamerica, Iquitos. WCS, DICE, UNAP, Iquitos, Brasil.

Albuquerque, N.I., Contreras, C.C., Alencar, S., Meirelles, C.F., Aguiar, A.P., Moreira, J.A. & Packer, I.U. 2009. Propriedade da carne crua e perfil de ácidos graxos do pernil de catetos (*Tayassu tajacu*) alimentados com torta de babaçu (*Orbignya phalerata*). *Arquivo Brasileiro de Medicina Veterinária e Zootecnia*, 61(6): 1419–1427.

Alencar, F.H., Yuyama, L.K.O., Varejão, M.J.C. & Marinho, H.A. 2007. Decisive and consequences of the alimentary insecurity in Amazonas: the influence of the ecosystems. *Acta Amazônica*, 37(3): 413–418.

Archimede, H. & Garcia, G.W. 2010. A guide to the use of sugar cane and its by-products as animal feed: a manual for farmers and livestock production specialists. Infinity Sales and Services and GWG Publications, Trinidad and Tobago. 135 p.

Baia Junior, P.C., Guimarães, D.A.A. & Le Pendu, Y. 2010. Non-legalized commerce in game meat in the Brazilian Amazon: a case study. *Revista de Biologia Tropical,* 58(3): 1079–1088.

Basiron, Y. 2007. Palm oil production through sustainable plantations. *European Journal of Lipid Technology,* 109: 289–295.

Bodmer, R.E. 2000. Integrating hunting and protected areas in the Amazon. *In:* N. Dunstone and A. Entwistle (editors). *Future priorities for the conservation of mammals. Has the panda had its day?* Cambridge University Press, Cambridge, UK.

Boyfield, K. 2010. Dispelling the myths: Palm oil and the environmental lobby. Adam Smith Institute, London, UK. 4 p.

Butler, R.A. & Laurence, W.F. 2009. Is oil palm the next emerging threat to the Amazon? *Tropical Conservation Science,* 2(1): 1–10.

Cavalcante Filho, M.F., Miglino, M.A., Machado, G.V., Bevilacqua, E. & Neves, W.C. 1998. Estudo comparativo sobre o suprimento arterial do estômago do queixada (*Tayassu pecari*) e do cateto (*Tayassu tajacu*) (Linnaeus, 1789). *Brazilian Journal of Veterinary Research and Animal Science,* 35(1).

Clement, C.R., Lleras Peres, E. & Van Leeuwen, J. 2005. O potencial das palmeiras tropicais no Brasil: Acertos e fracassos das últimas décadas. *Agrociencias,* 9(1-2): 67–71.

Comizzoli, P., Peiniau, J., Dutertre, C., Planquette, P. & Aumaitre, A. 1997. Digestive utilization of concentrated and fibrous diets by two peccary species (*Tayassu peccari*, *Tayassu tajacu*) raised in French Guyana. *Animal Feed Science Technology*, 64(2-4): 215–226.

Corley, R.H.V. & Tinker, P.B. 2003. *The oil palm.* 4th ed. Blackwell Science, Oxford, UK. 562 p.

Corley, R.H.V. 2009. How much palm oil do we need? *Environmental Science and Policy*, 12: 134–139.

EMBRAPA [Empresa Brasileira de Pesquisa Agropecuária]. 1991. Centro Nacional de Pesquisa de Suínos e Aves. Tabela de composição química e valores energéticos de alimentos para suínos e aves. 3rd ed. CNPSA, EMBRAPA, Concórdia, Brazil. 97 p. *Documentos*, no. 19.

Farias-Filho, R.V., Rabello, C.B., Da Silva, E.P., Lima, M.B. & Sousa, G.S. 2006. Avaliação da torta de dendê no desempenho de frangos de corte de 21 a 35 dias e de 35 a 42 dias de idade. *In: Anais Zootec* 2006, Recife, Brazil.

FEDEPALMA. No date [online]. Oil palm production area in the world. Available at http://www.fedepalma.org/statistics.shtm#produccion Accessed 3 November 2011.

Ferreira, M.E.M. 1999. Modelos log-normal e markoviano para estudo da evolução de abundância em uma floresta de babaçu. MSc thesis. Universidade Federal de Santa Catarina, Florianópolis, Brazil. 126 p.

Fitzherbert, E.B., Struebig, M.J., Morel, A., Danielsen, F., Brühl, C.A., Donald, P.F. & Phalan, B. 2008. How will oil palm expansion affect biodiversity? *Trends in Ecology and Evolution*, 23(10): 538–545.

Friends of the Earth. 2005. The oil-for-ape scandal – How palm oil is threatening the orang-utan. Friends of the Earth, London, UK.

Garcia, G.W., Young, G.G., Amour, K.M., James, D., Lallo, C.H.O., Mollineau, W., Roopchand, A., Spencer, M., Prosper, M.A., Ganessingh, N., Rooplal, R., Gayan, N., Steil, A., Xande, A., Bemelmans, A., Nogueira Filho, S.G. Guimaraes, D., Gálvez, H. & Mayor, P.A. 2005. The Collared Peccary/Pakira/Javelina/Catto/Catete/Porco de Monte/Taitetu/Sajino/Quenk [*Pecari tajacu*, *Tayassu tajacu*] Booklet & Producers' Manual. *Wildlife Farmers' and Producers' Booklet* No. 2. The Open Tropical Forage-Animal Production Laboratory [OTF-APL], Department of Food Production, Faculty of Science and Agriculture, UWI, St Augustine. GWG Publications, Champs Fleurs, Trinidad and Tobago.

Gómez, A.S., Benavides, C.I. & Diaz, C.M. 2007. Evaluación de torta de palmiste (*Elaeis guineensis*) em alimentación de cerdos de ceba. *Facultad de Ciencias Agropecuarias,* 5(1): 54–63.

Gonzalez, F., Smulders, F.J.M., Paulsen, P., Skewes, O. & Konig, H.E. 2004. Anatomical investigations on meat cuts of guanacos (*Lama guinicoe* Muller, 1776) and chemical composition of selected muscles. *Wiener Tierarztliche Monatsschrift,* 91: 77–84.

Hartley, C.S.W. 1988. *The oil palm*. 3rd ed. Tropical agriculture Series. Longman Singapore Publishers, Singapore. 761 p.

Hoffman, L.C. 2000. The yield and carcass chemical composition of impala (*Aepyceros melampus*), a southern African antelope species. *Journal of the Science of Food and Agriculture,* 80: 752–756.

Hoffman, L.C., K. Smit and N. Muller. 2008. Chemical characteristics of blesbok (*Damaliscus dorcas phillipsi*) meat. *Journal of Food Composition and Analysis,* 21: 315–319.

Hoffmam, L.C., Mostert, A.C., Kidd, M. & Laubscher, L.L. 2009. Meat quality of kudu (*Tragelaphus strepsiceros*) and impala (*Aepyceros melampus*): Carcass yield, physical quality and chemical composition of kudu and impala longissimus dorsi muscle as affected by gender and age. *Meat Science*, 83: 788–795.

Holzer, Z., Aharoni, Y., Brosh, A., Orlov, A., Veenhuizen, J.J. & Kasser, T.R. 1999. The effects of long-term administration of recombinant bovine somatotropin (Posilac) and Synovex on performance, plasma hormone and amino acid concentration, and muscle and subcutaneous fat fatty acid composition in Holstein-Friesian bull calves. *Journal of Animal Science*, 77: 1422–1430.

Jensen, B.B. 2001. Changes in bacterial populations in the ileum of pigs. pp. 181–200, *in:* A. Piva, K.E. Bach Kudsen and J.E. Lindberg (editors). *Gut Environment of Pigs*. Nottingham University Press, Loughborough, UK

Koh, L.P. & Wilcove, D.S. 2008. Is oil palm agriculture really destroying tropical biodiversity? *Conservation Letters*, 1: 60–64.

Lopes, R., Cunha, R.N.V., Rodrigues, M.R.L., Teixeira, P.C., Rocha, R.N.C. & Lima, W.A.A. 2008. Palmáceas. pp. 767–786, *in:* A.C.S. Albuquerque & A.G. Silva (editors). *Agricultura Tropical: quatro décadas de inovações tecnológicas, institucionais e políticas*. Vol. 1. *Produção e produtividade agrícola*. Embrapa Informação Tecnológica, Brasília, DF, Brazil.

Lorenzi, H., Souza, H.M., Medeiros Costa, J.T., Cerqueira, L.S.C. & Behr, N. von. 1996. *Palmeiras no Brasil: nativas e exóticas.* Editora Plantarum, Nova Odessa, Brazil. 303 p.

Marchiori, A.F. 2001. Composição e propriedades físico-química da carne de javali e suíno comercial. MSc thesis. Universidade Estadual de Campinas/UNICAMP, Campinas, São Paulo, Brazil. 83 p.

Marinho, M., Meireles, M.V. & Souza, A.V.G. 2004. Determinação da microbiota do trato gastrointestinal de avestruzes (*Struthio camelus*), criados na região noroeste do estado de São Paulo, submetidos à necropsia. *Arquivos Instituto Biológico,* 71(3): 267–271.

Melville, P.A., Cogliati, B., Mangiaterra, M.B.B.C.D., Ruz, M.P., Alves, C.M., Matsuda, L., Kim, A. & Benites, N.R.

2004. Determinação da microbiota presente na cloaca e orofaringe de avestruzes (*Struthio camelus*) clinicamente sadios. *Ciência Rural*, 34(6): 1871–1876.

Mendes, A. 2008. Fornecimento de uréia na dieta de catetos (*Pecari tajacu*) e uso de isótopo estável ^{15}N como marcador para estimativa da síntese de nitrogênio microbiano. PhD thesis. Centro de Energia Nuclear na Agricultura da Universidade de São Paulo, Piracicaba, Brazil. 102 p.

Monteiro, C.A., Mondini, L. & Costa, R.B.L. 2000. Mudanças na composição e adequação nutricional da dieta familiar nas áreas metropolitanas do Brasil (1988–1996). *Revista de Saúde Pública*, 34(3): 251–258.

Nelson, P.N., Webb, M.J., Orrell, I., Van Rees, H., Banabas, M., Berthelsen, S., Sheaves, M., Bakani, F., Pukam, O., Hoare, M., Griffiths, W., King, G., Carberry, P., Pipai, R., McNeill, A., Meekers, P., Lord, S., Butler, J., Pattison, T., Armour, J. & Dewhurst, C. 2010. Environmental sustainability of oil palm cultivation in Papua New Guinea. *ACIAR Technical Reports,* No. 75. Australian Centre for International Agricultural Research, Canberra, Australia. 66 p.

Nogueira-Filho, S.L.G. 1999. Criacao de Caititu e Queixada, Centro de Producoes Tecnicas [CPT], Depto. DE Producao Animal/ESALQ/USP, Piracicaba, Sao Paulo, Brazil. A booklet with accompanying VHS Video. 70 p.

Oil World. 2008. Oil World Annual. ISTA Mielke, Hamburg, Germany.

Oliveira, A.C.B., Cantelmo, O.A., Pezzato, L.E., Ribeiro, M.A.R. & Barros, M.M. 1997. Coeficiente de digestibilidade aparente da torta de dendê e do farelo de coco em pacu (Pieractus mesopotamicus). *Revista UNIMAR*,19(3): 857–903.

Oliveira, A.C.B., Pezzato, L.E., Barros, M.M. & Granner, C.A.F. 2008. Digestibilidade aparente e efeito macro-microscópico em tilápia do Nilo (*Oreochromis niloticus*) arraçoados com torta de dendê. *Brasilian Journal of Animal Science*, 27(2): 210–215.

Oliveira, F.S., Frias, D.F.R., Kozusny-Andreani, D.I., Martins, L.L., Delfini, A. & Toniollo, G.H. 2009. Microbiota intestinal em cutias criadas em cativeiro (*Dasyprocta azarae*, Lichtenstein, 1823). *Ciência Animal Brasileira*, 10(2): 660–662.

Oluwafemi, R.A. & Akpodiete, O.J. 2010. Carcass characteristics and meat quality of weaner pigs fed palm kernel cake-based rations. *Electronic Journal of Environmental Agricultural and Food Chemistry,* 9(1): 123–128.

Onwudike, O.C. 1986. Palm kernel meal as a feed for poultry. 3. Replacement of groundnut cake by palm kernel meal in broiler diets. *Animal Feed Science and Technology*, 16(3): 195–202.

Onwudike, O.C. 1988. Palm kernel meal as a feed for poultry. 4. Use of palm kernel meal by laying birds. *Animal Feed Science and Technology*, 20(4): 279–286.

Pascoal, L.A.F., Miranda, E.C. & Silva-Filho, F.P. 2006. O uso de ingredientes alternativos em dietas para peixes. *Revista Eletrônica Nutritime*, 3(1): 284–298.

Peres, C.A. 2000. Effects of subsistence hunting on the vertebrate community in Amazonian forests. *Conservation Biology,* 14: 240–253.

Peres, C.A. 2001. Synergistic effects of subsistence hunting and habitat fragmentation on Amazonian forest vertebrates. *Conservation Biology,* 15: 1490–1505.

Pérez, P., Maino, M., Guzmán, R., Vaquero, A., Köbrich, C. & Pokniak, J. 2000. Carcass characteristics of llamas (*Lama glama*) reared in Central Chile. *Small Ruminant Research*, 37: 93–97.

Projeto PROFAMA 109/2008 FAPESPA/SEDECT/UFPA/ Embrapa. 2008. Produção animal a partir de recurso faunístico da Amazônia: Criação de *Tayassu tajacu* um avanço ao Bionegócio. 22 p.

Ramalho Filho, A. & Motta, P.E.F. 2010. Contexto e objetivos do zoneamento agroecológico para a cultura da palma de óleo nas áreas desmatadas da Amazônia Legal. pp. 19–22, *in:* A. Ramalho Filho, P.E.F. Motta, P.L. Freitas & W.G. Teixeira (editors). *Zoneamento agroecológico, produção e manejo para a cultura da palma de óleo na Amazônia.* Embrapa Solos, Rio de Janeiro, Brazil.

Ramalho Filho, A., Motta, P.E.F., Naime, W.J., Gonçalves, A.O. & Teixeira, W.G. 2010. Zoneamento agroecológico para a cultura da palma de óleo nas áreas desmatadas da Amazônia Legal. pp. 57–68, *in:* A. Ramalho Filho, P.E.F. Motta, P.L. Freitas & W.G. Teixeira (editors). *Zoneamento agroecológico, produção e manejo para a cultura da palma de óleo na Amazônia*. Embrapa Solos, Rio de Janeiro, Brazil.

Ramos, E.M., Da Silva, A.M., Campos, F.S., Matos, R.A. & Santos, D.O. 2009. Rendimento de carcaça e de cortes comerciais de queixadas criados em cativeiro. *Boletim Centro de Pesquisas de Processamento de Alimentos*, 27(2): 225–230.

Revilla, J. 2002. *Plantas úteis da Bacia Amazônica.* Vol. II. INPA/SEBRAE, Manaus, Brazil.

Robinson, J.G. & Bodmer, R.E. 1999. Towards wildlife management in tropical forests. *Journal of Wildlife Management, Menasha*, 63: 1–13.

Rosenthal, E. 2007. Once a dream fuel, palm oil may be an eco-nightmare. *The New York Times,* 31 January 2007. Available at http://www.nytimes.com/2007/01/31/business/worldbusiness/31biofuel.html Accessed 03 November 2011.

Rostagno, H.S., Albino, L.F.T., Donzele, J.L., Gomes, P.C., Ferreira, A.S., Oliveira, R.F. & Lopes, D.C. 2000. Tabelas brasileiras para aves e suínos: composição de alimentos e exigências nutricionais. UFV, Viçosa, Brazil. 141 p.

Rhule, S.W.A. 1996. Growth rate and carcass characteristics of pigs fed on diets containing palm kernel cake. *Animal Feed Science and Technology*, 61: 167–172.

Schwarz, F.J., Schams, D., Ropke, R., Kirchgessner, M., Kogel, J. & Matzke, P. 1993. Effects of somatotropin treatment on growth performance, carcass traits, and the endocrine system in finishing beef heifers. *Journal of Animal Science*, 71: 2721–2731.

Silva, F.N., Pinheiro, M.J.P., Bezerra Neto, F. & Braga, A.P. 2002. Características da carcaça e análise químico-bromatológica da carne de catetos (*Tayassu tajacu*) submetidos a quatro níveis de proteína bruta em condições de cativeiro. *Caatinga,* 15(1/2): 57–60.

Thoenes, P. 2006. Biofuels and Commodity Markets – Palm Oil Focus. FAO Commodities and Trade Division. Food and Agriculture Organization of the United Nations. Available at http://www.fao.org/es/ESC/common/ecg/122/en/full_paper_English.pdf Accessed 17 January 2012.

USDA [United States Department Agriculture]. 2006. Official Statistics, USDA Estimates. Available at http://www.fas.usda.gov/oilseeds/circular/2006/06-02/table9.pdf Accessed 10 November 2011.

Valdares Filho, S. de C., Magalhães, K.A., Rocha Júnior, V.R. & Capelle, E.R. 2006. *Tabelas brasileiras de composição de alimentos para bovinos.* 2nd ed. UFV, Viçosa, Brazil. 329 p.

Wisneiwski, A. & Melo, C.F.M. 1981. Babaçu e a crise energética. Embrapa Amazônia Oriental, Belém, Brazil. 25 p.

Zylbersztajn, D., Marques, C.A.S., Nassar, A.M., Pinheiro, C.M., Martinelli, D.P., Adeodato Neto, J., Marino, M.K. & Nunes, R. 2000. Reorganização do agronegócio do babaçu no estado do Maranhão. Relatório técnico. Grupo Pensa-USP, São Paulo, Brazil. 120 p.

Chapter 15
Sustainable and competitive use as livestock feed of some co-products, by-products and effluents generated in the bio-ethanol industry

Harold Patino[1], Bernardo Ospina Patiño[2], Jorge Luis Gil[2] and Sonia Gallego Castillo[2]
[1] Universidad Federal de Río Grande del Sur – UFRGS, Porto Alegre, Brasil.
[2] CLAYUCA - CIAT, Cali, Colombia.
E-mail for correspondence: b.ospina@cgiar.org

ABSTRACT

A combination of factors, including rapid increase in fossil fuels prices, climate change effects and especially the need to provide rural jobs, is catalysing a growing interest in biofuel production. Biofuel processing operations need to meet technical, social and environmental sustainability parameters. Technical aspects are usually met, considering the vast array of options already available. The social aspects are more easily met when farmer groups are included as full participants in operations. Satisfying the environmental sustainability parameters is more difficult, as high volumes of effluent are generated as by-products. These by-products can be converted into co-products for use in animal feeding programmes. The Rural Social Biorefineries (RUSBI) approach, as presented in this chapter, for the production and local use of biofuels includes value-added management of co-products and residues generated. In this approach, the organic content of the effluents is flocculated and agglomerated through the use of a biopolymer-based technology, and the flocculated biomass is used to prepare nutritional supplements for ruminants. The use of these supplements in feeding experiments with ruminants has allowed net weight gains in calves and steers of 350–550 g/day, with better economic efficiency than feeding programmes based on commercial nutritional supplements. Transforming biofuel effluents into nutritional supplements for animal feeding is a sound approach to reducing or eliminating contamination of soils and waters, reducing the high costs involved in the management of the high volumes of effluents generated, and generally improving the overall energy and economic efficiency of the biofuel processing operation.

INTRODUCTION

In recent years, the problems associated with the increasing production and use of fossil fuels (such as national security, pollution and global warming) have prompted discussion about the real contribution of biofuels in reducing greenhouse emissions, and how to minimize the impacts caused by the eventual change of land use into food supply and socioeconomic development of rural communities (Walter and Leal, 2010). Today it is considered that the sustainability of biofuels depends on the fulfilment of prerequisites in three dimensions: economic, environmental and social. Bioethanol production in developing countries will have to prioritize the social dimension to ensure aggregate income and social inclusion of the rural communities involved. The growing global demand for biofuels may create new economic opportunities in rural areas, associated with the production, use and marketing of biofuels. Rural communities can also derive income from the processing of by-products and co-products of biofuels, such as high-protein livestock feeds and fertilizers (UNDESA, 2007).

Despite the wide variety of raw materials available for production of first generation ethanol, more than 90 percent of current world ethanol production is made from maize and sugar cane. However, there is increasing interest in the use of unconventional raw materials that have good levels of sugar or starch, good agronomic productivity, tolerance to low soil fertility, pest and disease resistance and resistance to environmental stress conditions, such as cassava (*Manihot esculenta* Crantz), sweet potato (*Ipomoea batatas*), sweet sorghum (*Sorghum bicolor* Moench), Jerusalem artichoke (*Helianthus tuberosus* L.), arrowroot (*Maranta arundinacea* L.), biri (*Canna edulis*), yam bean (*Pachyrhizus tuberosus*), yam (*Discorea* spp.), taro (*Colocasia esculenta*) and taioba or tannia (*Xanthosoma sagittifolium*) (Patino *et al.*, 2009). These crops are produced on small farms and therefore their use in ethanol production schemes needs

MAIN MESSAGES

- **Satisfying the environmental sustainability parameters in biofuel processing operations is a challenge, as high volumes of effluent are generated as co-products.**
- **The Rural Social Biorefineries (RUSBI) approach for the production and local use of biofuels includes value-added management of co-products and residues generated.**
- **The organic content of the effluents is flocculated and agglomerated through the use of a biopolymer-based technology, and the flocculated biomass is used to prepare nutritional supplements for ruminants.**
- **The use of these supplements in feeding experiments with ruminants has allowed net weight gains in calves and steers of 350–550 g/day, with better economic efficiency than feeding programmes based on commercial nutritional supplements.**
- **Transforming biofuel effluents into nutritional supplements for animal feeding is a sound approach to reducing or eliminating contamination of soils and waters, reducing the high costs involved in the management of the high volumes of effluents generated, and generally improving the overall energy and economic efficiency of the biofuel processing operation.**

to include the implementation of associative structures of production, public policies to add value to the product and appropriate management of co-products, by-products and effluents to minimize environmental impact.

The Latin American and Caribbean Consortium to Support Research and Development of Cassava (CLAYUCA), the Universidade Federal do Rio Grande do Sul (UFRGS), Brazil, and collaborators have been working over the past five years on the development of a technology platform known as the Rural Social Bio-refineries (RUSBI), to promote local production and use of ethanol (ETOH) (96% v/v) using cassava, sweet potato and sweet sorghum as raw material. The ethanol can be used as fuel for farm machinery and implements (tractors, irrigation pumps, power generators, clean-cook stoves, etc.) or sold in public or private niche markets at higher prices (social ethanol, pharmaceutical companies, green plastic industries, etc.). In this approach, wastes and effluents are converted into products that can be used to develop nutritional supplements for animal feed.

The RUSBI approach is not a technical package designed for biofuel production in large-scale commercial enterprises. On the contrary, RUSBI is an approach for small-scale production and local uses of biofuel, as a strategy to promote agricultural and economic development of those billions of farmers around the world living in marginal areas and facing a lack of resources, especially energy. RUSBI is meant to address the needs of these people and become an alternative model for promoting more inclusive, equitable bioenergy development efforts. The production of the biofuel is not considered the final product, as is the case of the commercial, large-scale operations. In the RUSBI approach, the biofuel becomes an intermediate objective that allows farmers groups to have access to energy, and to use this new energy-security status for implementing other agro-industrial transformation processes, adding value to their agricultural products and creating new employment and income opportunities. These combine to help reduce levels of poverty and to improve standards of living. The RUSBI approach focuses on developing an alternative approach for biofuels production that overcomes the social inequalities that characterize the modern, large-scale, commercial biofuel operations that are booming around the world, characterized by the limited participation of the farmers in the distribution of the benefits, acting merely as providers of raw material for the distilleries (Ospina, Gallego and García, 2009).

The RUSBI approach for biofuel production

The RUSBI approach for the production of biofuels has five technical components that integrate modern concepts of agricultural management, process engineering and effluent management (Figure 1).

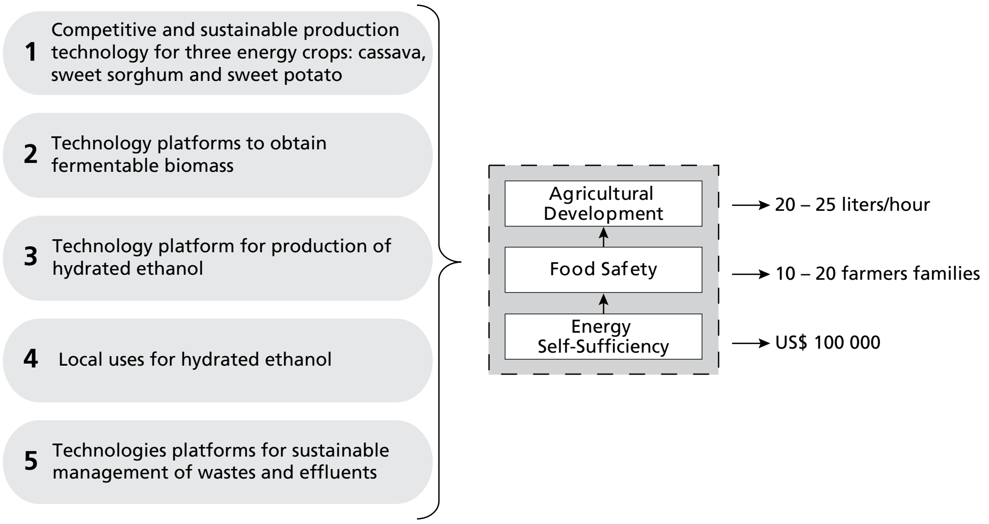
The end objective of the RUSBI approach is to promote agricultural development, food safety and energy self-sufficiency within small-scale farmer groups and rural communities, living in isolated, marginal areas. The scale of the rural social biorefinery is small to facilitate the participation of poor farmer groups: the capacity of the ethanol distillery is 20 to 25 litre/hour, so groups of 10 to 20 farming families could produce enough cassava, sweet potato or sweet sorghum to run the plant, with a total investment cost for a rural community of around US$ 100 000.

The various elements in a RUSBI are presented in Photo 1. They comprise:

- a drying plant and a refining unit to produce cassava and sweet potato flour, and a milling section to produce sweet sorghum juice,
- a pilot plant to produce ethanol (96 percent), with a capacity to produce 20 L/hour, and
- a plant for treating the effluents.

The biorefinery equipment also includes a stationary engine to generate bio-electricity, and a cooking stove. Both use the ETOH as fuel.

FIGURE 1
Technical components of the Rural Social Biorefineries (RUSBI) approach



a) Cassava or sweet potato flour milling and refining plant *b) Ethanol processing plant* *c) Effluents treatment plant*

Photo 1
Equipment included in a typical Rural Social Biorefinery (RUSBI)

The process for production of the ETOH in the RUSBI approach is shown in Figure 2 When the feedstock is cassava, biofuel can be obtained from cassava flour or from cassava roots. When cassava flour is used, the roots are first processed into refined flour, which is then converted into a slurry or liquid biomass by adding water.

Incubation conditions (pH and temperature) are adjusted to prepare for the hydrolysis and fermentation steps. The operating conditions include: pH of fermentation medium 4.5, adjusted with hydrochloric acid (30 percent m/m); substrate concentration 30 percent; fermentation time 72 hours; with 0.23 percent urea, 0.5 percent enzyme and 0.33 percent yeast. The fermented must is then passed through the distillation columns to obtain the ETOH, with the vinasse as the co-product.

When fresh cassava roots are used, the roots are grated into a pulp with very fine particle size to facilitate the hydrolysis and fermentation stages. In this method, less water is required for the process but the fermented biomass requires a filtering step to reduce the high fibre content prior to the distillation step. One important difference in the process when cassava flour is used instead of fresh cassava roots is that two co-products are generated during the milling and refining processes, which can be used in animal feed, helping to offset the additional cost of processing the cassava roots into flour.

Hydrolysis is one of the most important phases of the process, converting starches into fermentable sugars, which are then metabolized by yeast during fermentation, producing bio-ethanol. The enzymatic hydrolysis or saccharification is catalysed by enzymes whose function is to break down large starch molecules to produce units of glucose. For hydrolysis of starches, two methods can be used: liquefaction, saccharification and conventional fermentation (LSF); or simultaneous hydrolysis and fermentation (SHF).

The LSF method consists of the starch being first liquefied, then converted into glucose (saccharification), and finally fermented using a yeast (*Saccharomyces cerevisiae*). The thermostable enzymes used in the liquefaction and saccharification steps are, respectively, alpha-amylase and

FIGURE 2
Flowchart for the production of ethanol in the RUSBI approach

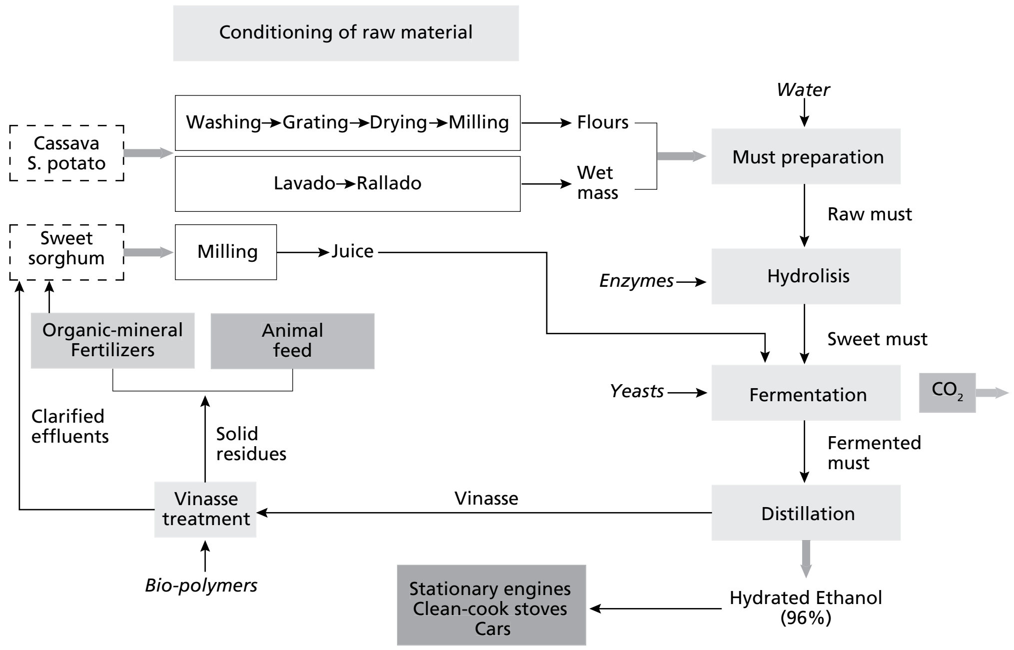


TABLE 1
Operating conditions in the early stages of hydrolysis and fermentation of the conventional process (LSF) for biofuel production

Parameter	Hydrolysis		Fermentation
	Liquefaction	Saccharification	
T (°C)	82–86	65–70	32
pH	5.7–6.0	4.3	4.5

Source: Genencor International web site (www.genencor.com)

TABLE 2
Operating conditions of the simultaneous hydrolysis, fermentation and sacharification process (SHF) for biofuel production

Parameter	Hydrolysis (Liquefaction + Saccharification)	Fermentation
T (°C)	30–33	30–33
pH	4.0–4.5	4.5

Source: Genencor International Web site (www.genencor.com)

gluco-amylase. Operating conditions conventionally used for this method are given in Table 1.

In the SHF method, a mixture of enzymes is used to carry out the saccharification of starch without the liquefaction stage. In this method, special enzymes are used (StarGen™), that are able to perform the hydrolysis stage at room temperature, and allow the combination of the saccharification and fermentation stages in one single step, because they work under the same conditions of temperature and pH as the yeast (*Saccharomyces cerevisiae*). The operating conditions for this method are given in Table 2.

The RUSBI approach to producing bio-ethanol is based on the SHF method, seeking to reduce processing time, power consumption and installation costs, since it does not need installation of a heat exchanger. After the SHF step is finished, a fermented mash is obtained. To separate the ethanol from this mash, a distillation stage is required, in which the ethanol evaporates at 78 °C. The ethanol vapours are captured and condensed, yielding ETOH and leaving the vinasse (Ospina *et al.*, in press).

BIO-ETHANOL PRODUCTION TRIALS WITH THE RUSBI APPROACH

The work conducted by CLAYUCA with the RUSBI model for production of biofuel has focused on the optimization of the enzymatic hydrolysis of starch in cassava (Cajamarca, 2009), and on estimation of the efficiency in the production of bio-ethanol from cassava flour, by calculating the mass and energy balances in the process (Martínez, 2009). Some of the tests conducted with cassava flour and cassava roots for the production of ETOH using the SHF method at room temperature are presented in Table 3.

Management of the vinasse co-product resulting from the bio-ethanol production process

The operation of a biofuel production process, such as ETOH from cassava, generates a large quantity of effluent

TABLE 3
Production of ethanol from cassava roots and cassava flour in a CLAYUCA RUSBI pilot plant

	Cassava flour	Fresh cassava roots
Raw material		
Cassava refined flour (kg)	120	300
Enzymes (Stargen) (kg)	0.600	0.380
Yeast (Ethanol red) (kg)	0.400	0.500
Urea (kg)	0.300	0.300
Water (kg)	400	450
Products generated		
Ethanol 96% v/v (Litre)	44.7	48
Vinasse (Litre)	630	801
Quantitative analysis		
Yield (L ethanol/t cassava flour)	372.5	
Yield (L ethanol/t cassava root)		**160**
Yield (L ethanol/ha)(1)	2660	4000
Ethanol production efficiency(2) (%)	61	89
Ratio of vinasse to ethanol (v/v)	14.1	16.7

Notes: (1) Average cassava yield = 25 t/ha. (2) Production/theoretical conversion.

as a by-product of the process. This effluent, known as vinasse, is produced in large volumes and needs to be managed properly in view of its potential environmental effects and energy costs parameters. The vinasse has the form of a dark organic liquid, with very low pH (3.5 to 4.3), and is the result of the fermentation of carbohydrates (sugar cane and sweet sorghum juices, cassava and sweet potato slurry) and subsequent distillation of the fermented mash. The vinasse contains a high percentage of organic matter (organic acids and dead yeast), minerals (mainly potassium, calcium, magnesium and sulphur) and non-fermentable constituents of the raw material (Patino *et al*., 2007).

On average, for every litre of ethanol obtained, between 10 and 15 litre of liquid effluent are generated, depending on the feedstock used, the time of harvest, the grinding process, the fermentation and distillation technology, the soil type and fertility level, and other parameters (Mutton, Rosetto and Mutton, 2010.). In a CLAYUCA biorefinery, the ethanol production from cassava had a ratio of vinasse to ethanol equivalent to 14:1 (Del Ré *et al.,* 2010).

Vinasse has historically been used as a fertilizer, with Brazil being the pioneer in the development of fertirrigation systems using sugar cane vinasse. The use of the vinasse has improved sugar cane productivity in Brazil (Penatti, 2007) through chemical (Leal *et al.,* 1983), biological (Matiazzo and da Gloria, 1985) and soil physical benefits (Gloria and Orlando Filho, 1983), as well as reduced fertilization costs. However, the excessive and continuous application of vinasse in agricultural soils can create serious problems in terms of cane quality (Silva, Pozzi de Castro and Magro, 1976) and water source contamination (Gloeden *et al.,* 1990).

The use of vinasse in fertirrigation takes two general forms. The first is to use the vinasse directly after leaving it to cool, as the temperature at which the product leaves the distillation process is above 70 °C. After cooling, and with the addition of minerals (N, P), the vinasse is used to directly irrigate the fields.

The second method is to reduce the water content to facilitate its incorporation or mixing with other raw materials. This can be accomplished by physical processes, such as sedimentation in ponds (this can take between 48 and 72 hours). Alternatively, chemicals can be added, such as polymers that accelerate the process of flocculation and coagulation, precipitating the solids in the vinasse more rapidly. The polymers are diluted to 1 part per thousand and added to the vinasse, which results in a rapid clarification response (Orts *et al*., 2007).

In addition to use as fertilizer, the vinasse can also be concentrated by evaporation or drying and used in the preparation of animal feed products (Albers, 2007) or in the production of fertilizers (Barbosa *et al*., 2006). However, this alternative has limitations due to the high energy cost of the concentration process. An alternative use of the vinasse is the production of biogas (methane) through anaerobic fermentation by methanogenic bacteria, which also reduces the environmental impact of the vinasse by reducing its biological oxygen demand (BOD) and chemical oxygen demand (COD) (Peres, 2007; Zhang *et al.,* 2010). The vinasse has also been used for single-cell protein production in aerobic fermentation systems (Murakami *et al*., 1993; Diaz, Maria Gualtieri and Semprun, 2003; Cazetta and Celligoi, 2006). Another alternative for the management of the vinasse is the production of compost for use as fertilizer. This latest technology, despite its potential as an environmentally friendly process, requires high investments in area, capital and time for its operation.

TRANSFORMATION OF CO-PRODUCTS, BY-PRODUCTS AND EFFLUENTS INTO NUTRITIONAL SUPPLEMENTS FOR ANIMAL FEEDING

In bio-ethanol production with the RUSBI approach, vinasse treatment is done using electrically charged chemicals known as biopolymers, which are made from starch and have been used to ensure the slow release of minerals contained in fertilizers, to reduce erosion, to increase the penetration of water in the soil and to produce fertilizer-coated seeds. When the biopolymers are introduced into solutions that have basic pH and with high loads of ionic solids, flocculation and coagulation of the organic load occurs. Once the organic matter contained in the vinasse is flocculated, coagulated and removed, the clarified water can be used for other purposes in the biorefinery (irrigation, washing, cleaning, etc.). Figures 3 and 4 present the

FIGURE 3
Process for management of vinasse in the RUSBI approach

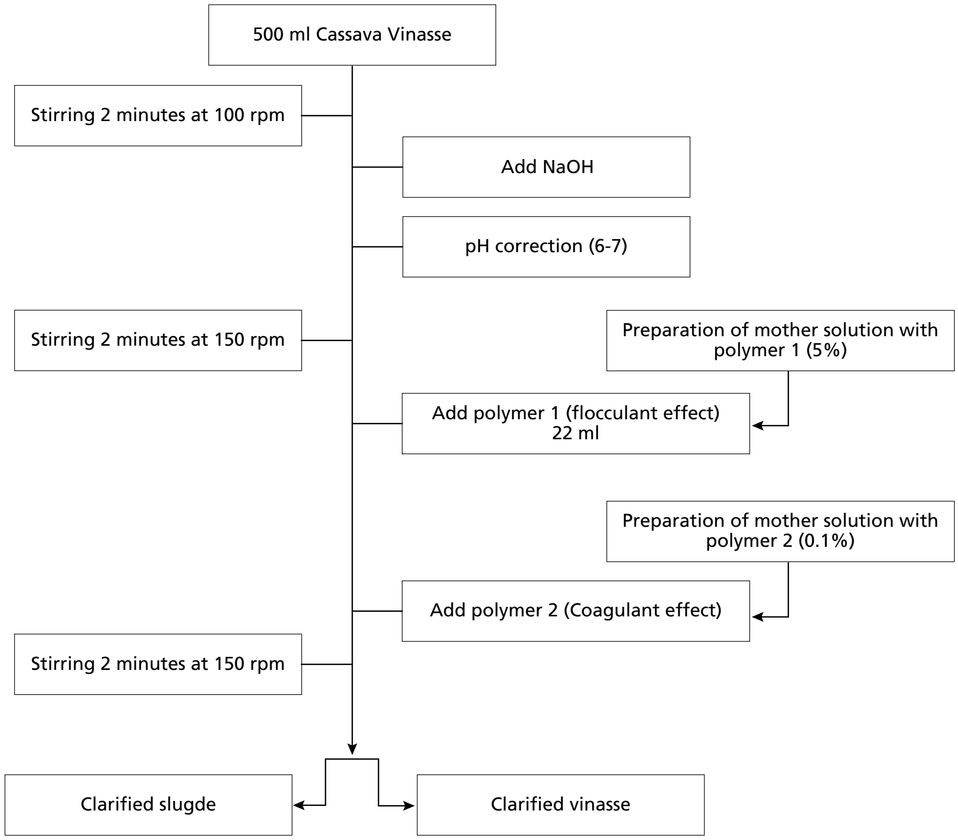
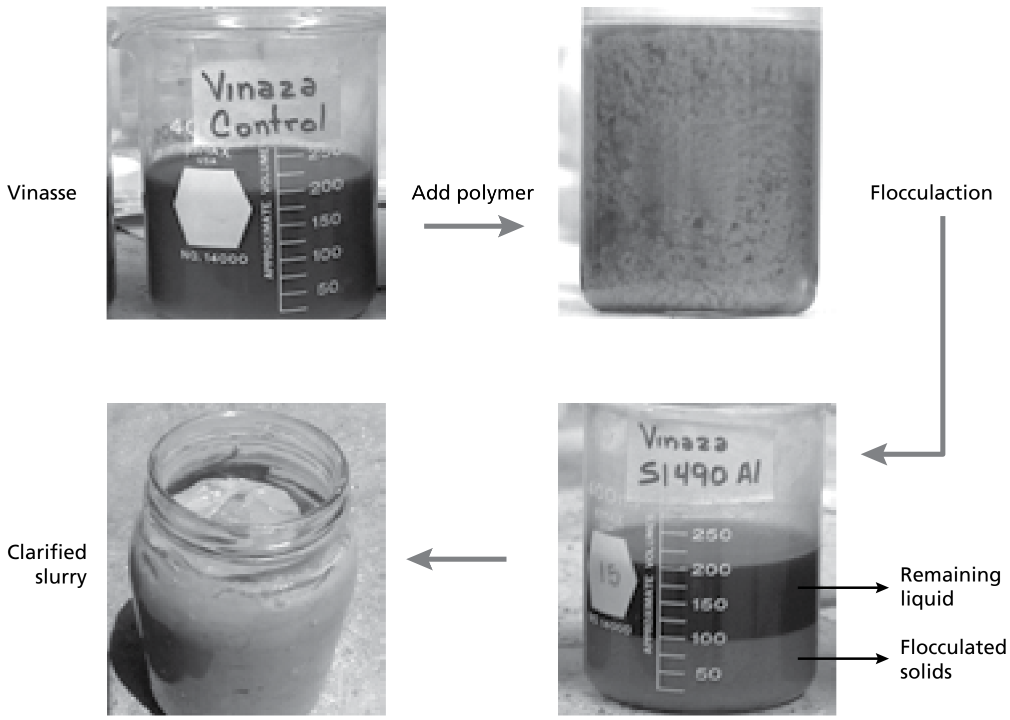


FIGURE 4
Scheme of the steps followed in the RUSBI approach to convert vinasse into clarified vinasse and clarified sludge



flocculation and coagulation processes, which result in two products, vinasse and clarified sludge. Table 4 shows the bromatological composition of four types of vinasse. Table 5 presents the minerals and nutrient content of pure vinasse, clarified vinasse and clarified sludge, from sugar cane biofuel processing.

CLAYUCA-CIAT, in partnership with Soil Net (Soil Net LLC, Polymers Solutions, a private company in the United States) and Universidade Federal do Rio Grande do Sul, Porto Alegre (UFRGS; a Brazilian University), has developed new potential solutions and alternatives for sustainable, competitive management of the effluents generated in biofuel distilleries. One of these alternatives is protein and energy supplementation for ruminants by mixing the vinasse with cassava products (roots and foliage). The nutritional supplements developed with vinasse have been oriented principally to feed ruminants. The composition and characteristics of products can be adjusted to suit the age and type of animal to be fed.

The organic matter contained in the flocculated sludge is mixed with other products and co-products obtained during the process, such as cassava and sweet potato leaves and stems, and sweet sorghum bagasse. Other components that are included are urea, minerals and additives. The formulation of the nutritional supplement is scientifically designed with the help of a computer program to obtain a final product that is competitive, nutritionally balanced and highly efficient in the feeding of ruminants. Photo 2 presents the different steps required to prepare the nutritional supplement.

Organic matter removed from vinasse, together with products and co-products from biofuel processing (cassava and sweet potato leaf and stalks; sweet sorghum and sugar cane bagasse) and other ingredients such us urea, minerals and additives, are combined to provide a balanced protein, mineral and energy supplement for ruminants (Patino *et al.,* 2007; Martin, 2009). The supplements can be presented in different forms, depending on the animal feeding programme: multinutritional blocks, pellets or meal (Photo 3).

In the preparation of the multinutritional blocks, the ingredients (bagasse, molasses, vinasse, urea, sodium

TABLE 4
Chemical composition and *in vitro* dry matter digestibility (IVDMD) of four types of vinasse (all values are percentages except for trace minerals)

Nutriment/Parameter	Vinasse source			
	Cassava	Sugar cane	Sweet potato	Sweet sorghum
Dry matter	8.5	13.0	2.6	3.4
Organic matter	93.5	–	92.8	90.8
Crude protein	11.6	2.0	12.5	7.2
Starch	0.7	–	–	–
Ether extract	4.9	0.4	22.3	0.8
Crude fibre	60.4	–	27.0	
IVDMD	64.7	–	–	–
Ash	5.2	32.3	7.2	9.2
Total Digestible Nutrients	–	–	74.5	77.8
P	1.42	0.45	0.39	–
Ca	5.38	1.04	0.50	–
K	1.49	2.08	1.9	–
Mg	0.40	0.24	0.63	–
S	0.48	0.30	0.18	–
Na	0.34	–	0.31	–
Zn (ppm)	40	–	44	–
B (ppm)	16	–	10	–
Mn (ppm)	104.5	–	58	–
Fe (ppm)	3305	86	584	–
Cu (ppm)	14	1	17	–
Al (ppm)	3121	–	–	–

Sources: CLAYUCA, 2008

TABLE 5
Nutritional content of the products obtained in clarification of sugar cane vinasse

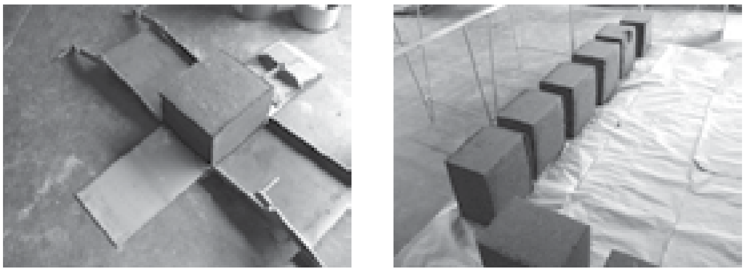
Product	P total	K total	Ca total	Mg total	S	Fe	Cu	Na	Zn	Crude protein	OM
			(%)				(mg/kg)			(%)	
Sugar cane vinasse	2.97	10.24	0.88	1.14	1.23	986	6.0	3.066	54.0	7.0	56.8
Clarified sugar cane vinasse	0.00	1.06	0.48	0.12	0.14	32.0	0.0	366.0	3.0	0.8	6.8
Sugar cane clarified sludge	2.75	2.99	14.26	0.20	9.30	525	47.0	467.0	19.0	5.2	27.5

Note: OM = organic matter. *Source:* CLAYUCA, 2007.

Step 1. Raw material preparation

Step 2. Mixing ingredients

Step 3. Pressing



Step 4. Drying 8-15 days

Photo 2
Outline of the steps followed to prepare the nutritional supplements in the RUSBI approach

bentonite and minerals) are first weighed and mixed in a horizontal mixer. The order of introduction of ingredients is defined to avoid losses of molasses by adhesion to the walls of the mixer and to enhance chemical reactions and heat generation, thus ensuring that the mix is in a form suitable for the block compaction operation. First the bagasse, minerals and sodium bentonite are mixed. Then a solution of urea, diluted in the vinasse and molasses, is incorporated in the mix. Finally, the calcium oxide is incorporated. The mixture is agitated for 15 minutes until homogenous. The blocks are formed by pressing 18 kg of the mixture in a steel mould under compaction pressure of 2000 kg/cm^2 for 5 minutes. Finally, the blocks are removed from the mould and placed in a shaded area to dry for one week. For transportation and commercialization, the blocks are packed in cardboard boxes.

In the preparation of supplements specifically for cattle feeding, co-products from sugar cane-based ethanol can be included at between 50 and 80 percent. Tables 6 and 7 present the components and nutritional composition of two products for ruminants: a multinutritional block and a mineral salt block, made with co-products from sugar cane-based biofuel processing, using the RUSBI process. Table 8 presents the bromatological composition of the two nutritional supplements (energy and protein), prepared as blocks with salt.

TABLE 6
General characteristics of a block nutritional supplement

Raw material	Inclusion level (%)	Nutritional composition (%)	
Pre-digest bagasse	25.10	Crude protein	24.0
Vinasse sludge	36.82	NPN (max.)	3.9
Fly ash	4.32	TDN	33.0
Molasses	9.89	Ca	2.21
Other ingredients	23.87	P	1.00
Total	100.00	S	0.36

Notes: Other ingredients comprise urea, NaCl, flowers of sulphur, dicalcium phosphate, calcium oxide, sodium bentonite, micromineral premix. NPN = Non-protein nitrogen; TDN = Total digestible nutrients.
Source: CLAYUCA, 2009

As indicated in Table 8, the two nutritional supplements have TDN equivalence, but they differ in the percentage of protein. Both the blocks and the meals are recommended for use in situations in which the available pastures have protein contents below 6 percent and where the TDN:CP ratio exceeds 8. Also, the energy supplements are recommended with better quality pastures, with protein content over 8 percent. All the nutritional supplements were formulated to obtain a balance of 10 to 11 percent between con-

Photo 3
Different forms of nutritional supplement and standard packaging

TABLE 7
General characteristics of a nutritional supplement in meal form

Raw material	Inclusion level (%)	Nutritional composition (%)	
Pre-digest bagasse	24.45	Crude protein	24.0
Clarifications sludge	35.86	NPN (max.)	0.9
Filter cake	4.63	TDN	34.0
Molasses B	9.90	Ca	2.21
Other Ingredients	25.16	P	1.00
Total	100.00	S	0.36

Notes: Other ingredients comprise NaCl, flowers of sulphur, dicalcium phosphate, sodium bentonite, urea, mineral premix. NPN = Non-protein nitrogen; TDN = Total digestible nutrients.
Source: CLAYUCA, 2009

TABLE 8
Bromatological composition of two nutritional supplements (energy and protein), elaborated as blocks and meals, using vinasse and other products and co-products from sugar cane-based biofuel processing

Nutrients	Protein supplement		Energy supplement	
	Block	Meal	Block	Meal
Dry matter (%)	78.0	93.4	79.0	94.2
Organic matter (%)	67.6	59.4	67.7	65.0
Crude protein (%)	33.1	39.5	9.6	17.2
Fat	0.8	2.2	1.3	1.6
Total Digestible Nutrients (TDN)	65.5	64.3	69.9	65.5

Source: Ruminants Nutrition Laboratory-LANUR. UFRGS, 2007. Pers. Comm.

sumption of degradable protein in the rumen and energy consumption (TDN), in animals grazing pastures of low to medium quality. At least 25 percent of the total nitrogen in the nutritional supplement is from true protein and the rest is non-protein nitrogen.

The multinutritional blocks based on co-products and effluents from ethanol production are very attractive in the market because they have good palatability and good levels of protein and energy (i.e. TDN) (Loaiza, 2008; Torres, 2010). The microbiological quality of the nutritional supplements developed by CLAYUCA was measured under differing storage conditions to check if they were meeting the quality standards and guidelines established by Colombian legislation (implemented through Instituto Colombiano Agropecuario – ICA). The products were stored according to the conditions recommended in the local standards for Good Manufacturing Practices for Food (BPFA), which require that after 40 days the nutritional supplements must retain their intrinsic characteristics and have good microbiological status.

TABLE 9
Microbiological analysis of multinutritional blocks made with co-products and effluents from sugar cane-based ethanol production

Analysis	Nutritional block	ICA Specification
Count of mesophile aerobic micro-organisms (CFU/ml)	1×10^6	Up to 1 000 000 CFU/g
Count of fungi (CFU/mL)	<10	Up to 100 000 CFU/g
Count of yeast (CFU/mL)	1×10^4	Up to 100 000 CFU/g
MPN of faecal coliforms per mL	Not detected	Absence
Salmonella in 25 g	Not detected	Negative in 25 g

Notes: CFU = Colony Forming Units; MPN = most probable number. *Source*: ICA Microbiological Laboratory. Pers. Comm.

Photo 4
Cattle eagerly consuming nutritional blocks made with co-products and effluents from sugar cane-based ethanol processing

Table 9 shows the results of the microbiological analysis of multinutritional blocks made with co-products and effluents from sugar cane-based ethanol production. The microbiological count indicated absence of *Salmonella* and faecal coliforms over 40 days, as well as a constant low fungal count (<10) (Loaiza, 2008; Torres, 2010). Palatability tests of the nutritional supplements were also conducted by CLAYUCA, with positive responses from the animals in terms of consumption rates for the blocks and liveweight gain. These nutritional supplements are very attractive for the animals due to their high palatability (Torres, 2010), and also for their high levels of dry matter digestibility (Loaiza, 2008).

Another feature of the block preparation process for nutritional blocks is an increase in crude protein content as levels of vinasse increase in the formulation. This change is due to the presence of yeast residues in the vinasse, which enrich the nutritional value of the product (Loaiza, 2008). These positive features make the nutritional blocks a very attractive product, with great market potential in the animal feed sector. Photo 4 shows the acceptance of the product by the animals.

BIO-ECONOMIC ANIMAL FEEDING TRIALS WITH THE NUTRITIONAL SUPPLEMENTS

The quality and efficacy of nutritional supplements made with co-products and effluents from sugar cane-based and cassava-based ethanol processing has been tested in bio-economic animal feeding trials.

In a commercial test with calves with initial weight of less than 200 kg, a nutritional supplement was fed for 90 days to complement a *Pennisetum purpureum* grass basal diet. Average weight gains per animal per day of 0.602 kg were obtained, almost double the average weight gains (0.316 kg/animal/day) obtained by the animals before starting the supplementation. The short duration of this feeding trial does not allow firm conclusions to be made. The main objective of this experiment was to make a first evaluation regarding the acceptance of the block by the animals, and to have an initial estimate of the consumption potential. The animals in the study consumed the block from the first day of exposure, without any rejection related to the smell or taste of the product. The nutritional block retained its structure during the whole supplementation period.

Another trial aimed at assessing the consumption and weight gain of heifers on pasture, supplemented with protein supplements prepared from cassava root and leaf flour, and vinasse from sugar cane-based biofuel production (Gil *et al.,* 2007). The study included 20 replacement Holstein heifers, with an average initial weight of 168 kg, divided into two groups of 10 animals each. One group was used for evaluating the protein supplement based on cassava and vinasse, and the other to assess the use of a commercial supplement. The experiment lasted for 120 days (September to December). Four grazing plots planted with an African star grass (*Cynodon nlemfluensis*), with an average area of 5518.5 m^2 for each plot, were used in the rotation of the animals (each group used two pastures). The forage dry matter on offer was on average 2320.5 kg DM for each grazing plot, equivalent to 4204.9 kg DM/ha. The trial was conducted at a site near Palmira, Valle, Colombia.

Animals were distributed randomly into two groups: the first group received 1.5 kg/day/animal of a commercial concentrate (18 percent protein and 67 percent TDN), and the second group received 1.0 kg/day/animal of supplement based on cassava and vinasse (21 percent protein and 56 percent TDN). The group receiving the vinasse-based supplement was given a period of 10 days to accustomize to the product. Weighing was conducted every 21 days and supplement consumption assessed, taking into account the daily supply of supplement. The commercial supplement and the supplement based on cassava were weighed in the morning. In the afternoon, the feeders were reviewed to collect and weigh the wastes or leftovers. In both cases, the consumption of supplements was complete. The assessment of the weight gains indicated that those animals that consumed the supplement of cassava and vinasse had better performance than the animals given the commercial product. Weight gains were on average 0.48 kg/day whereas the commercial concentrate gave weight gains averaging 0.36 kg/day (P <0.05). The slightly higher weight gain obtained by the animals consuming the cassava-based supplement could be explained by the higher protein content of the cassava-based supplement and the better ratio of nutrients (rumen degradable protein vs TDN).

Another trial was carried out in the Cauca River Valley, classified by Köppen as tropical climate. The experimental area consisted of 17 paddocks divided with electric fences, each approximately 0.25 ha, planted with an African star grass (*Cynodon plectostachyus*). Each paddock had an automatic water supply and a feeder for the nutritional supplement. Rotational paddock grazing was used, with about 2 days of occupation and 17 days of rest. The pastures were fertilized with 80 kg P_2O_5/ha/yr and 50 kg N/ha/yr. During the dry season, the pastures were uncompacted and irrigated. A total of 71 steers of undefined breed, aged approximately 24 months, and with an initial average live weight of 234 kg, were used. The treatments evaluated consisted of a conventional mineral supplement and a protein-mineral block supplement (Table 10).

Statistical analysis of the data obtained indicated that daily weight gains of animals consuming the nutritional blocks was 21 percent higher than the weight gains among the animals consuming the mineral supplement (P <0.05) (Table 11). The weight gains obtained indicate the potential of the nutritional supplements for use in animal feeding. The economic efficiency parameter was also positive. The average daily weight gain of animals consuming multi-nutritional blocks was 94 g/day higher than in the animals supplemented with mineral blocks to 6 percent. This improved efficiency represented a 17 percent increment on gross margin (US$ 0.69 vs US$ 0.59), making it an attractive option for cattle producers (Table 12). The objective of this experiment was to validate the option of developing a nutritional supplement that could give the animal not only minerals, but also protein and some energy. The question that this experiment was trying to answer was "Is it possible to have a complete nutritional supplement (minerals, energy, protein) that was competitive relative to the mineral supplements available in the market?"

TABLE 10
Composition of nutritional supplements offered to cattle

Nutrient	Conventional mineral blocks (6%)[(1)]	Multi-nutritional blocks
Crude protein (%)		24
Non-protein nitrogen (NPN) (% max.)		3.85
Total Digestible Nutrient (TDN) (g/kg)		330
Sodium chloride (%)	38.52	19.62
Phosphorus (g/kg)	60.0	10.04
Calcium (g/kg)	120.0	22.12
Magnesium (g/kg)	0.5	1.91
Sulphur (g/kg)	6.0	3.60
Copper (ppm)	2500	82
Zinc (ppm)	8000	247
Iodine (ppm)	150	5.96
Cobalt (ppm)	40	0.82
Selenium	100	0.82

Notes: Mineral block analysis data from www.somexnutricion.com.
Source: CLAYUCA, 2009

TABLE 11
Initial live weight, final live weight and average daily weight gain of grazing animals with nutritional supplementation

Variables	Treatments	
	Multinutritional block	Mineral block 6%
Initial weight (kg)	231.5	235.4
Final weight (kg)	273.2	269.8
Weight gain (g/day)	541 a	447 b

Notes: a, b = different suffixes indicate a significant difference based on the Tukey Test (P <0.05). *Source*: CLAYUCA, 2009

TABLE 12
Weight gains and economic benefits from grazing animals with nutritional supplementation

Parameter	Multi-nutritional block	Mineral block 6%
Average initial weight (kg)	231.0	235.0
Average final weight (kg)	273.2	269.8
Average weight gain (kg)	42.20	34.80
Duration of trial (days)	78	78
Average daily weight gain (kg/day)	0.541	0.446
Price live kg (US$)	1.47	1.47
Price average daily weight gain (US$)	0.80	0.66
Supplement consumed (kg/day)	0.177	0.071
Nutritional supplement consumed (kg)	1046.6	1565.02
Costs of nutritional supplement (US$)	0.10	0.06
Gross margin (US$)	0.69	0.59

Source: CLAYUCA, 2009

ECONOMIC VIABILITY OF THE USE OF NUTRITIONAL SUPPLEMENTS IN ANIMAL FEEDING

The economic viability of the use of nutritional supplements for animal feeding based on the by-products and co-products from sugar cane and cassava biofuel operations will depend on the cost of producing the nutritional supplements and their price competitiveness in relation to the price of similar products available in the commercial market. Table 13 presents the complete cost of producing a nutritional supplement (block) using the RUSBI approach.

In the Colombian cattle sector, the use of nutritional supplements is common, although the percentage of cattle growers that uses them is still limited. In some cases, the transportation costs to the areas with large cattle operations increases the final costs of the nutritional supplements. The products commercially available are presented in the form of blocks, with a weight of 25 kg each, usually including molasses and urea. As of August 2011, the cost of a multinutritional block was 28 000 Colombian pesos (US$ 15.55). The unit cost of nutritional block is US$ 0.622/kg from the RUSBI process, while commercial blocks are 52 percent more expensive. This large margin implies tremendous market potential for these nutritional supplements in the animal feed sector.

The technical and economic feasibility of using by-products and co-products coming from a sugar cane- or cassava-based biofuel operation to produce supplements for animal feeding has been demonstrated. It is possible to use the nutritional supplements in animal feeding programmes, with good results in terms of both biological and economic

TABLE 13
Production costs for a nutritional block, based on producing 100 nutritional blocks of 15 kg each

Parameter	Unit	Quantity	Unit cost (US$)	Total cost (US$)
Variable costs				
Bagasse	Kilogram	289.5	0.13	37.64
Fly ash	Kilogram	300	0.016	4.80
Clarified sludge	Kilogram	375	0.05	18.75
Molasses	Kilogram	150	0.19	28.50
By-products total cost		1114.5		89.69
Inputs				
Urea	Kilogram	60	0.49	29.40
Mineral salt	Kilogram	185.25	0.72	133.38
Sulphur	Kilogram	3	2.10	6.30
Polymer	Kilogram	2.25	7.30	16.43
Calcium oxide	Kilogram	135	0.55	74.25
Inputs total cost		385.5		259.76
Total costs of raw material		1.500.0		349.45
Other costs				
Electric power	kwh	13.78	0.11	1.52
Water	m^3	6	0.75	4.50
Qualified operator 1	Hour	4.78	2.13	10.18
Qualified operator 2	Hour	4.78	4.27	20.41
Total other costs				36.61
Selling cost				
Packaging	1 cardboard box	100	0.06	6.00
Transport	US$/block	100	0.05	5.00
Total cost of sales				11.00
Total variable costs				397.05
Fixed costs				
Administration (5% of production cost)				18.81
Unforeseen (5% of production cost)				18.81
Maintenance (5% of production cost)				18.81
Total fixed costs				56.43

Total production cost per 100 blocks of 15 kg = 453.48.
Total production cost per kilogram of nutritional block = 0.302

Source: CLAYUCA, 2009

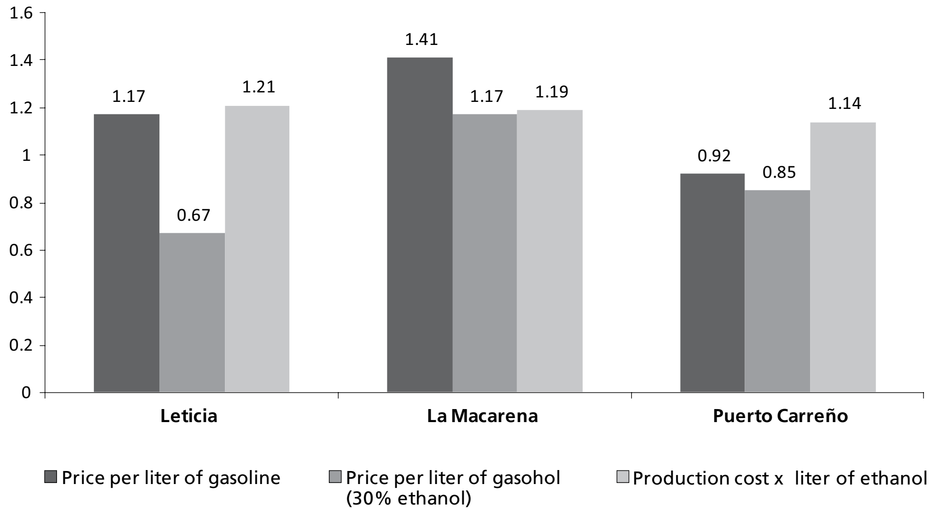
efficiency. It is also feasible to establish market linkages with the animal production sector and to position the nutritional supplements based on their competitive production price in comparison with commercially available products. However, the work conducted by CLAYUCA and collaborating agencies, institutions and private sector companies has focused on a strategy designed to promote biofuel production and use by small-scale communities and farmer groups, i.e. the RUSBI approach. In this sense, the initial beneficiaries of the technology developed for the preparation and use of the nutritional supplements will be the commercial groups that are already operating the bio-ethanol distilleries, with large volumes of effluents that need to be managed with economic and environmental efficiency. The small-scale rural communities, cooperatives and farmer groups that the RUSBI approach is targeting will not be able to compete with the large-scale biofuels distilleries and sugar cane operations. The objective of the RUSBI approach is not to enter this market. What RUSBI aims to achieve is to add value to the biofuels that can be produced by small-scale farmers, promoting local use, for their own consumption, or for commercialization in local markets, supported by the government (social ethanol) or by private-sector initiatives. The sustainable, competitive management of the effluents becomes a plus component of this approach, with potential to help farmers improve the feeding systems for their animals and increase incomes.

For facilitating access by target farmers to the potential benefits of these technologies, the rural social biorefineries have to be promoted and established in the rural areas, and this process may still require some time, considering the initial investment required (around US$ 100 000 for a 300 L/day distillery). CLAYUCA has been working on generating the data required to convince and sensitize national and local governments, rural development agencies and the donor community, regarding the importance of supporting strategies aimed at promoting production and local uses of biofuel by poor farmers, located in remote villages, and lacking access to any source of energy. A study was conducted (Gomes, 2010) to evaluate the technical and economic feasibility of the implementation of a rural social biorefinery (500 L/day) in three rural areas of Colombia (Puerto Carreño, La Macarena and Leticia), with problems of high energy costs as a consequence of their total dependence on fossil fuel. The study concluded that the implementation of the rural social biorefinery project is viable in one region (La Macarena), in which all the gasoline consumed has to be brought in from other regions, at very high cost. In contrast, in other regions, due to their proximity to other countries (Venezuela and Brazil) that guarantees a steady supply of gasoline at lower prices, the bio-ethanol produced in the rural social biorefinery would not be competitive (Figure 5).

Another study, conducted in Brazil (Rosado, 2009), evaluated the economic feasibility of establishing a small-scale biorefinery, with a specific focus on small rural properties. The viability of the operation of the distillery was analysed for both a cooperative system and an association type of organization. The operation of the biorefinery as part of a productive model within a large rural property was also simulated. The analysis considered two raw material options: sugar cane plus sweet sorghum, and sweet potato plus sweet sorghum.

The economic analysis was carried out through a cash flow simulation for a period of ten years, including the taxation element as appropriate for each case. Different levels

FIGURE 5
Comparison of gasoline, gasohol and ethanol prices in 3 regions of Colombia



Source: Gomes, 2010.

of funding of the project were also tested, with differentiated parameters for small and large properties. Parameters estimated included the Net Present Value (NPV) and the Internal Rate of Return (IRR). The biorefinery as a cooperative model was found the best option, with or without external financing, as compared with the associative model, mainly due to a lower tax regime for the cooperatives.

KNOWLEDGE GAPS AND FUTURE RESEARCH NEEDS

The use of co-products, by-products and effluents from bio-ethanol production as nutritional supplements in animal feed has been receiving increased attention in recent years, and although information about the technology options for treatment and use of these effluents is available, there are still some areas where more information, knowledge and research is required.

The huge volume of effluents generated in the biofuels processing operation is a major challenge. There is an urgent need to develop processing technologies that could reduce considerably the large volumes of effluents generated. In large-scale operations, with high capital investments, this problem could be reduced to a large extent by evaporation of the effluents.

In operations at smaller scale, with poor farmer groups and rural communities, this option is more difficult to implement because they generally lack the resources to invest in processes that demand high capital and energy costs, and a long time scale. Composting is one example of these options. Substantial capital investments are required, large areas need to be allocated, and a good composting process usually requires from 70 to 90 days. Therefore, it is very important to work on developing technologies that help to reduce the amount of water used in the production of the biofuel and, consequently, the volume of vinasse that is generated.

An area that needs to strengthened, one that could help to improve the overall efficiency of the biofuel production process, is the conversion of vinasse into biogas, through an anaerobic fermentation process. The biogas generated could then be used in the distillery, helping to reduce energy costs. The residue could be used as fertilizer. Finding and developing new bacterial strains that could perform under the hard conditions and characteristics of the vinasse would be a major breakthrough for this process.

Another area, in which there is still a large gap in knowledge and information, is in the identification and validation of products that can act as flocculants and agglomerants of the organic load present in the vinasse. Up to now, the most common products in use are the biopolymers. CLAYUCA, UFRGS and SoilNet have had very good results using biopolymers. This has been the basis for the technologies developed for the formulation of the nutritional supplements described in this chapter. Although the cost of the biopolymers is low (only 1.5 grams is required to prepare 1 kilogram of nutritional supplement, and only 2.4 percent of the costs of producing 1 ton of nutritional supplements is due to the biopolymers), the primary constraint is that the biopolymers are usually produced by multinational companies, and there could be some difficulties in importing and distributing them, especially if they are intended for use by small-scale, resource-poor farmer groups. Thus, there is a need to develop alternative products that would function in the same manner as the biopolymers, but that could be produced and distributed locally and thus be more easily purchased by small farmer groups.

Finally, there is a need to develop and refine technology protocols for the production of products with greater value-added, with good economic potential for use in the animal feed market. The use of biofuel co-products in the production of single-cell protein is one example of an emerging technology. CLAYUCA and UFRGS have already obtained promising results in pilot activities in which sugar cane-based vinasse has been used as a substrate to grow yeast (*Candida utilis*), with acceptable performance parameters. The biomass harvested from this process is the basis for an excellent yeast cream with high protein percentages, that could have multiple uses in animal feeding and industry. This is an exciting field that will probably grow very rapidly in the coming years.

CONCLUSIONS

The effluents and different products and co-products generated during the biofuel production process have very good potential as nutritional supplements in animal feed, especially for cattle. Co-product use in this way is an activity that helps to improve the overall economic efficiency of the biofuel production process and has positive impacts on the environment. Different technology options exist and their application to biofuel production enterprises is very easy, especially in large-scale, commercial operations with enough economic resources available for implementation.

Scenarios of biofuel production and use with small-scale farmer groups and rural communities, in which the RUSBI approach is applied, have been presented in this chapter. The technologies that are currently available for the management of the effluents through transforming them into nutritional supplements for animal feed (such as flocculation with biopolymers) need to take into account the specific context of the target groups, which usually have limited financial resources for investing, and with low educational levels so learning to handle and assimilate sophisticated processes and technologies takes time. The technologies offered have to be simple, efficient and sustainable.

The transformation of the effluents from biofuel processing into nutritional supplements for use in animal feed, especially cattle, could be a very important strategy to promote social inclusion and more active participation of the farmers in the distribution of the benefits obtained in the biofuels value chain, helping them to improve the feeding systems of their animals, and to gain more control over their natural resources through a more sustainable management of the wastes and residues generated in the biofuel processing operation.

BIBLIOGRAPHY

Albers, M. 2007. Tratamento da Vinhaça: Concentração e outros. *In:* Workshop Tecnologico sobre Vinhaça. Projeto Políticas Públicas FAPESP. Realizado em 10/10/2007, na FCA/UNESP – Campus Jaboticabal. Available at http://www.apta.sp.gov.br/cana/anexos/Position_paper_sessao4_monica_VS.pdf . Accessed 11 November 2011.

Barbosa, V., Durigan, A.M.P.R., da Gloria, N.A. & Mutton, M.A. 2006. Uso da vinhaça concentrada na adubação de soqueira de cana-de –açúcar. Revista da Sociedade dos Técnicos Açúcareiros e Alcooleiros do Brasil (Stab) Açúcar, Álcool e subprodutos, Piracicaba, 24(6): 26–29.

Cajamarca, J.A. 2009. Optimización de la hidrólisis enzimática para la producción de bioetanol a partir de yuca. Tesis de pregrado, Ingeniería Agroindustrial, Universidad Nacional de Colombia, Sede Palmira. Palmira, Colombia.

Cazetta, M.L. & Celligoi, A.P.C. 2006**.** Study of molasses/vinasse waste ratio for single cell protein and total lipids production by micro-organisms. *Revista Semanal: Ciências Exatas e Tecnológicas, Londrina,* 27(1): 3–10.

CLAYUCA [Consorcio Latinoamericano y del Caribe de Apoyo a la Investigación y al Desarrollo de la Yuca]. 2007. Valoración química de la vinaza de caña y el lodo clarificado. Documento interno de trabajo. Laboratorio de Servicios Analíticos de CIAT.

CLAYUCA. 2008. Valoración bromatológica y química de la vinaza de caña y vinaza de yuca. Documento interno de trabajo. Analytical Services Laboratory (ASL), CIAT/ Laboratorio de Servicios Analíticos de CIAT. Internal report.

CLAYUCA. 2009. Desarrollo de pruebas con animales para el uso de la vinaza como materia prima en la elaboración de suplementos para animales. Documento interno de trabajo.

Del Ré, D., Patiño, H., Ospina, B., Gallego, S. & Cajamarca, J.A. 2010. Efeito da diminuição na utilização de água sobre o rendimento na produção de etanol a partir de mandioca (*Manihot esculenta* Crantz) em micro-usinas [poster]. *In:* Simposio Estadual de Agroenergia. Reunioes Tecnicas de Agroenergia (3°), da Mandioca (10°) e batata-doce (2°) (Pelotas (RS), Brazil, 2010). Departamento de Zootecnia, UFRGS, and CLAYUCA, CIAT.

Diaz, M., Maria Gualtieri, M. & Semprun, A. 2003. Producción de proteína unicelular a partir de desechos de vinaza. *Revista de la Facultad de Farmacia*, 45(2): 23–26.

Gil, J.L., Campos, R., Giraldo, L., Ospina, H.P. & Perilla, S. 2007. Desarrollo y evaluación de un suplemento utilizando la planta integral de yuca y subproductos de la agroindustria de la caña de azúcar. *In*: IX ENICIP (Medellín, Colombia, 2007). Anais. Medellín: Universidad de Antioquia, 2007. 20: 623–623.

Gloeden, E., Cunha, R.C.A., Fraccaroli, M.J.B. & Cleary, R.W. 1990. The behaviour of vinasse constituents in the unsaturated and saturated zones in Botucatu aquifer recharge area. pp. 225–235, *in:* Proceedings of the International Seminar on Pollution, Protection and Control of Ground Water. Porto Alegre (RS), Brazil.

Gloria, N.A. & Orlando Filho, J. 1983. Aplicação de vinhaça como fertilizante. Boletim Técnico. Planalsucar. Piracicaba. 38 p.

Gomes, A.R. 2010. Avaliação de implementação de Biorefinarias Rurais e Sociais na Colômbia. Thesis for Master of Food Engineering. Universidade Técnica de Lisboa, Lisboa, Portugal.

Leal, J.R., Amaral Sobrino, N.M.B., Velloso, A.C.X. & Rossiello, R.O.P. 1983. Potencial redox e pH: variações em um solo tratado com vinhaça. *Revista Brasileira de Ciência do Solo. Campinas,* 7: 257–261.

Loaiza, J.K. 2008. Usos de los subproductos de la caña en la elaboración de dos suplementos nutricionales para rumiantes en el Valle del Cauca. Trabajo de pregrado. Universidad de Caldas, Manizales, Colombia.

Martin, P.C. 2009. El uso de residuales agroindustriales en la alimentación animal en cuba: pasado, presente y futuro. *Avances en investigación agropecuaria [La Habana Cuba],* 13(3): 2–10.

Martínez, G.M. 2009. Determinación de la eficiencia en la producción de bioetanol a partir de yuca mediante balances de materia y energía. Bachelor thesis in Food Engineering, Universidad Nacional de Colombia, Sede Palmira. Palmira, Colombia.

Matiazzo, M.E. & da Gloria, N.A. 1985. Efeito da vinhaça na acidez do solo. Revista da Sociedade dos Técnicos Açúcareiros e Alcooleiros do Brasil (Stab) – Açúcar, Álcool e Subprodutos, Piracicaba, SP, 4(2): 35–40.

Murakami, A.E., Moraes, V.M.B., Ariki, J., Junqueira, O.M. & Kronka, S.N. 1993. Levedura de vinhaça (*Saccharomyces cerevisae*) como fonte protéica na alimentação de frangos de corte. *Revista Societas Brasiliana Zootechnica,* 22(5): 876–883.

Mutton, M.A., Rosetto, R. & Mutton, M.J.R. 2010. Utilização Agricola da Vinhaça. pp. 423–440, *in:* L.A.B. Cortez (Editor). *Bioetanol de cana de açúcar: P&D para produtividade e sustentabilidade.* Blucher, São Paulo, Brazil.

Orts, W.J., Roa-Espinosa, A., Sojka, R.E., Glenn, G.M., Imam, S.H., Ercharler, K. & Pedersen, J.S. 2007. Use of synthetic polymers and biopolymers for soil stabilization in agicultural, construction and military applications. *Journal of Materials in Civil Engineering*, 19: 58–66.

Ospina, B., Gallego, S. & García, J.A. 2009. Bio-refinerías Rurales Sociales (BIRUS). Reunión Anual de Socios 2009. CLAYUCA, CIAT. Documento de trabajo. Palmira, Colombia.

Ospina, B., Gallego, S., Ospina, H. & Gil, J.L. In press. Production of bio-ethanol from cassava. *In:* B. Ospina and H. Ceballos (editors). *Cassava in the Third Millennium: Modern Production, Processing, Use and Marketing Systems.* CIAT for CLAYUCA. Publication expected in 2012.

Patino, H., Gil, J.L., Espinosa, J.D. & Loaiza, J.K. 2007. Protocolo para el desarrollo y la evaluación de suplementos nutricionales para rumiantes elaborados a partir de subproductos de la agroindustria de la caña de azúcar. Informe final. Cali, Colombia. 62 p.

Patino, H.O., Ospina, B.P., Gallego, S. & Payán, J.S. 2009. BIRUS – Biorefinarias Rurais Sociais. Uma proposta para o etanol social. pp. 283–298, *in:* 1° Simpósio Brasileiro de Agropecuária Sustentável. Agricultura, Pecuária e Cooperativismo. Viçosa (MG), Brazil, 2009. Memórias. Departamento de Zootecnia, Departamento de Economia Rural, Universidade Federal de Viçosa. Viçosa, Brazil.

Penatti, C.P. 2007. Vinhaça e seus efeitos no solo e na planta. *In:* Workshop Tecnologico sobre Vinhaça. Projeto Políticas Públicas FAPESP. Realizado em 10/10/2007, na FCA/UNESP – Campus Jaboticabal. Jaboticabal. Available at: http://www.apta.sp.gov.br/cana/anexos/Position_Paper_sessao3_claudimir.pdf Accessed 11 November 2011

Peres, C.S. 2007. Tratamento da vinhaça: biodigestão anaeróbia. *In:* Workshop Tecnologico sobre Vinhaça. Projeto Políticas Públicas FAPESP. Realizado em 10/10/2007, na FCA/UNESP – Campus Jaboticabal. Jaboticabal. Available at: http://www.apta.sp.gov.br/cana/anexos/Position_Paper_sessao5_clarita.pdf Accessed 11 November 2011.

Rosado, A.G.R. Jr. 2009. Análise da viabilidade econômica da produção de bioetanol em microdestilarias. Congresso Brasileiro de Custos (16:2009); Fortaleza, CE. Anais.

Silva, G.M. de A., Pozzi de Castro, L.J. & Magro, J.A. 1976. Comportamento agroindustrial da cana-de-açúcar em solo irrigado e não irrigado com vinhaça. pp. 107–122, *in:* IV Seminário Copersucar da Industria Açúcareira.

Torres, L.A. 2010. Elaboración de bloques nutricionales a partir de residuos de la agroindustria de la caña de azúcar. Thesis. Universidad de Caldas, Manizales, Colombia. 136 p.

UNDESA [United Nations Department of Economic and Social Affairs]. 2007. Small-scale production and use of liquid biofuels in sub-Saharan Africa: perspectives for sustainable development. UNDESA, New York, USA.

Walter, A. & Leal, M.R.L.V. 2010. Introducción. pp. 174–183, *in:* L.A.B. Cortez (Editor). *Bioetanol de cana de açúcar: P&D para produtividade e sustentabilidade.* Blucher, São Paulo, Brazil.

Zhang, Q.-H., Lu, X., Tang, L., Mao, Z.-G., Zhang, J.-H., Zhang, H.-J. & Sun, F.-B. 2010. A novel full recycling process through two-stage anaerobic treatment of distillery wastewater for bio-ethanol production from cassava. *Journal of Hazardous Materials,* 179(1-3): 635–641.

Chapter 16
Scope for utilizing sugar cane bagasse as livestock feed – an Asian perspective

S. Anandan and K.T. Sampath
National Institute of Animal Nutrition and Physiology, Bangalore India 560030
Corresponding author e-mail: anandsrp@yahoo.co.in

ABSTRACT
Sugar cane is one of the important commercial crops grown in tropical regions, including Asia, and is emerging as major feedstock for bio-ethanol production. Bagasse, the fibrous residue after extraction of juice from sugar cane, is an important co-product, generated in large quantities and with the potential to be used as a roughage source for ruminants. Currently, a major part of bagasse is used as a source of fuel in the sugar and jaggery production process. It is also used as raw material in board or paper manufacture. Use of bagasse for livestock feeding is very limited due to poor nutritive value and palatability. The low nutritive value of bagasse is mainly due to its high lignin content and low protein, energy and mineral content. Considerable research has been carried out to improve utilization of bagasse in various production systems, and for productive functions in different livestock species. Because of its low nutrient density and fibrous nature, bagasse cannot be used as sole feed to fulfil animal nutrient requirements, or even for maintenance, and has to be supplemented with other, high quality feeds. There is a need for economic analysis of the use of processed bagasse as feed as comparative price advantage of feed use vs non-feed use would be a decisive factor. Cost of conventional cereal straw used for feeding ruminants (paddy, wheat or sorghum) will also influence use of bagasse for livestock feeding. Policy decisions, such as subsidizing biofuels and tax concessions for sugar mills generating power, are other factors that can have a major negative impact on the usage of bagasse as a feed resource.

INTRODUCTION
Use of various agricultural commodities as raw materials for biofuels has a major impact on the usage patterns, leading to changes in crop acreage and cropping patterns. This, at times, could lead to fuel-food and fuel-feed conflicts, affecting local food and feed security. Depleting fossil fuel reserves, environmental concerns and long-term sustainability are factors that favour the promotion of biofuel production. Aggressive promotion of biofuels through policy interventions would lead to increases in the area of crops that serve as biofuel feedstocks and disturb the balance between food and feed and other crops. Sugar cane is a crop with multiple utility. Besides sugar production, it is one of the important feedstocks for ethanol production. Efficient utilization of biofuel co-products can mitigate the impact of food-feed conflicts and add value to the biofuel value chain. This crop is a major feed and fodder resource in sugar cane growing areas through its co-products and integrates well with dairy production (Rangnekar, 1986). Sugar cane bagasse is another co-product available in large quantities and, in view of a fodder deficit situation in countries like India, there is need to consider ways of optimizing its use as feed. The present status of and prospects for use of sugar cane bagasse as livestock feed in the Asian context is briefly reviewed in this chapter.

SUGAR CANE PRODUCTION AND CO-PRODUCTS
Sugar cane production trends over the last two decades (1990–2009) globally have shown that the area under sugar cane has expanded by 34 percent and production of sugar cane has increased by 53 percent. Brazil is the largest producer of sugar cane and India ranks next to Brazil in both area and production. Globally, Brazil has 33 percent of the area and 37 percent of production of sugar cane, while India has 21 percent of the area and accounts for 20 percent of global production. The Asian region has recorded an increase of 3 million hectare under cultivation and an increase in production of around 195 million tonne during the same period (1990–2009). The share of area and production of sugar cane in Asian region in the global context has remained in the range of 40 to 45 percent during the same period (FAOSTAT data). Within the Asian region, based on data for 2007–2009, India is the largest producer, accounting for about 50 percent of the region’s output, followed by China (18%), Thailand (10%), Pakistan (9%), Indonesia (4%) and the Philippines (4%) (Table 1).

MAIN MESSAGES

- **Bagasse is the fibrous co-product of the sugar processing industry, a major part of which is used as a fuel source in the sugar processing industry itself.**
- **The surplus bagasse available from sugar mills has the potential to be used as a roughage source in ruminants, with the major limitation on bagasse use being its low nutritive value, due to high fibre and low content of protein, energy and minerals.**
- **Using appropriate interventions – supplementation with limiting nutrients, treatment of bagasse, and a combination of the two approaches – will facilitate inclusion of bagasse up to 40 to 60% of the total diet to support various productive functions (milk, meat, maintenance and reproduction) in ruminants.**
- **Feed use versus non-feed use of bagasse would be dictated by relative economic advantage, and current usage and policies are in favour of non-feed uses.**

TABLE 1
Production trends in major sugar cane producing countries of Asia (million tonne)

Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
India	299	296	297	287	234	237	281	356	348	285
China	69	78	92	92	91	88	93	114	125	116
Thailand	54	50	60	74	65	50	48	64	74	67
Pakistan	46	44	48	52	54	47	45	55	64	50
Indonesia	24	25	26	25	27	29	29	25	26	27
Philippines	24	22	21	24	26	23	24	22	27	23
Asia	554	552	585	596	537	514	562	680	703	606
World	1257	1261	1329	1372	1333	1313	1415	1611	1729	1661

Source: FAOSTAT data.

TABLE 2
Composition of sugar cane and co-products (on a percentage dry matter basis)

	CP	EE	CF	Total ash	NDF	ADF	Lignin	Reference
Whole sugar cane	6.0	2.1	30.6	4.7	49.6	32.5	8.4	Dhage *et al*., 2009.
Bagasse	2.7	–	–	2.5	84.2	51.0	11.2	Krishnamoorthy, Singh and Kailas, 2005.
Bagasse	3.7	1.1	44.2	5.0	92.3	81.5	25.7	Nagalakshmi and Reddy, 2010.
Sugar cane tops	5.9	1.7	33.5	8.5	65.3	40.4	4.8	Naseeven, 1988.

Notes: CP = crude protein; EE = ether extract; CF = crude fibre; NDF = neutral-detergent fibre; ADF = acid-detergent fibre.

The major co-products of sugar cane are sugar cane tops, bagasse, molasses and filter mud, of which the first three are used as feed resources for livestock. The composition of the sugar cane and its co-products are shown in Table 2. Although no specific data are available regarding the usage pattern of these co-products, in most of the countries in South Asia, sugar cane tops are used as the main fodder for ruminants during the sugar cane harvesting season due to shortage of roughages. Even though molasses is a preferred feed resource, and there is a huge demand from the livestock sector, its availability for feeding livestock has always been a constraint, due to high demand for other industrial uses, chiefly for distilleries and export. FAO, through an expert consultation in 1986 reviewed available information related to use of sugar cane and co-products of the sugar industry for feeding livestock in sugar cane growing countries (FAO, 1988). The publication also provides information on alternative uses of sugar cane and co-products of sugar industry (see Paturau, 1988, and Alexander, 1988).

In the Indian context, the potential uses of sugar cane co-products include use in the production of paper and boards, moulded products, rayon-grade pulp, electric power, biogas, ethanol, furfural, food additives, animal feeds, soil amendments and fertilizers (Yadav and Solomon, 2006).This chapter reviews work done on sugar cane bagasse as livestock feed in the Asian context, and, wherever relevant, includes work carried out elsewhere.

Sugar cane bagasse

Sugar cane bagasse is produced in large quantities at the crushing units, either small-scale units at village level or large-scale sugar factories, and is used as fuel for heating boilers or generating steam. Sugar factories with efficient boilers and cane juice processing machinery have surplus bagasse. Part of the surplus bagasse is sold as fuel and

TABLE 3
Sugar cane bagasse production in Asian countries (million tonne)

Country	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
India	46.6	56.7	66	64.9	70.1	58	72.5	79.4	81.8	91.7	84.6
China	24.3	23.4	22.5	20.9	28.4	34.1	33.3	29.8	30.7	40.9	47.0
Thailand	13.3	15.6	16.6	12.1	15.7	18.4	17.4	18.7	16.1	23.3	19.5
Pakistan	11.4	12.0	6.6	8.8	10.8	13.2	14.5	9.2	10.6	14.2	16.3

Source: United Nations Statistics Division

to the board and paper industry. The feeding of bagasse to livestock is very limited. It has, however, been successfully used as drought feed. Average bagasse production is around 30 percent of the cane crushed and it is mainly used as fuel in the sugar factories (Rangnekar, 1986). Bagasse production in major sugar cane producing countries in the Asian region is presented in Table 3. Shortage of feed resources and high cost of conventional feeds have necessitated exploring alternate feed resources, like bagasse, which are available in plenty at affordable prices.

Of late, considerable research is exploring the possibility of utilizing bagasse as raw material for second-generation biofuels and alternative uses. At the same time, research on bagasse for utilization as a feed resource is unfortunately declining. This is evident from the number of publications appearing on the subjects "Bagasse" and "Bagasse and feeding" in the Commonwealth Agricultural Bureaux International (CABI) Animal Production Database over the last four decades. The number of publications on various uses of bagasse increased from 350 in 1972–1991 to 397 in 1992–2010, indicating continuing interest in bagasse, while publications related to bagasse and livestock feeding fell from 167 to 115 in the same periods.

Bagasse contains more than 60 percent of its dry matter in the form of cellulose and hemicellulose, and its degradability in the rumen is very poor. High levels of lignin, low levels of soluble carbohydrates and the relative absence of both fermentable nitrogen and by-pass protein result in low nutritive values for crop residues (Preston and Leng, 1984; Hamad and El-Saied, 1982; Sundstol, 1988). Sugar cane bagasse contains around 50 percent cellulose, 27.9 percent hemicellulose, 9.8 percent lignin and 11.3 percent cell contents (Kewalramani *et al.,* 1988). Pith, a co-product of bagasse obtained from bagasse-based paper mills, is nutritionally better than the bagasse as it is devoid of lignified rind and so has better digestibility. The components of bagasse are in their natural, resistant conformation, and hence susceptibility to enzymatic hydrolysis is extremely limited (Rivers, 1988).

There are basically three approaches to improving the nutritive value of bagasse: pre-treatment, supplementation and a combination. Most of the studies use the combined approach. As the ruminal degradability of bagasse is very low, some form of pre-treatment may be essential to enable the rumen microbes to digest the complex carbohydrates present and thus improve its degradability. Furthermore, as bagasse is low in energy, protein and minerals, it has to be supplemented to ensure optimum rumen fermentation, so as to fulfil the role of a basal diet. Studies conducted by researchers using different approaches, and their findings, are reviewed briefly. Although these approaches are discussed under separate headings, many of these involve a combination of approaches. In addition to the above approaches, Preston (1980) proposed fractionation of different components of sugar cane to ensure its optimal utilization, and a brief description of the approach is also given.

Fractionation of sugar cane

On observing the extremely low fermentability of sugar cane fibre in the rumen and the negative effect this has on voluntary intake of the overall diet, Preston (1980) developed a method for fractioning the juice and the residual fibre-sugar in the pressed stalk, so they can be treated as separate entities. The justification for this system is that the juice comprises soluble carbohydrates (sucrose, glucose and fructose) and is completely digestible by both ruminant and non-ruminant livestock and is thus a viable alternative for the starch in cereal grains. The sugar cane tops, and even the bagasse, may still contain appreciable amounts of sugars in the residual juice, and have a potential digestibility ranging between 50 and 60 percent. If adequately supplemented with fermentable nitrogen (urea or ammonia), these could have a nutritive value similar to Elephant grass. It can also be fed to small ruminants, which are able to select the sugar-rich pith, leaving the lignified rind as a source of fuel (Preston, 1988).

Pre-treatment of bagasse

It is well recognized that pre-treatment of the plant material is required to improve the nutritive value of lignocellulosic materials for livestock (Helmling *et al*., 1989). The pre-treatment could be physical, chemical, biological or combinations thereof, which would result in significant changes in the structural characteristics of the lignocellulosic matrix, resulting in better contact of microbial enzymes with fibre for improved digestion (Rolz *et al*., 1987). Of the various treatments, steam and alkali treatment have been most widely used by different researchers to improve the utilization of bagasse. Pre-treatment must meet the following requirements: (1) improve enzymatic hydrolysis, (2) avoid degradation or loss of carbohydrate, (3) avoid formation of products inhibitory to the subsequent hydrolysis and fermentation processes, (4) improve palatability, and (5) be cost-effective (Ye and Cheng, 2002).

Steam treatment

Major reasons for using steam as pre-treatment for improving the nutritive value of bagasse is the ready availability of steam at sugar plants, which could be easily used with minimum investment and, as it does not involve use of any chemicals, it is likely to be safe. The steam pressure treatment completely modifies the hemicellulose fraction of raw bagasse, changing it into more soluble components, but does not affect the lignocellulose components (Wong *et al*., 1974; Pate, 1982; Kling *et al.,* 1987). Replacement of maize silage with equal proportions of cubed hay and bagasse (steamed and pelleted with wood chips) resulted in similar energy intake, milk yield and protein content, but lowered milk fat and total solids in a bagasse-fed group of milch animals (Sekiguchi *et al*., 1981). Steam treatment of bagasse was found to improve its digestibility and acceptability to animals due to changes in colour, smell and palatability (Rangnekar *et al.,* 1982, 1986). Rumen dry matter degradability in Zebu cattle determined by the nylon bag technique for untreated, steam ammoniated (NH_3; 3%) and steamed bagasse was found to be 17, 20 and 31 percent against 35 percent in the control that contained cotton wool (de la Cruz, 1990). Heat treatment in the presence of water (solvolysis) or aqueous orthophosphoric acid at 2.9 percent w/w (phosphorolysis) was also used to increase the nutritional value of sugar cane bagasse for cattle feeding (Fontana, Ramos and Deschamps, 1995).

Steaming of fresh bagasse at a pressure of 15 kg/cm^2 for 10 minutes and fed at 50 percent of dietary dry matter in wethers resulted in improved digestibility and was found equivalent to wild grass. The estimated total digestible nutrients (TDN) value of steam-treated bagasse was 48.7 percent (Tanabe and Kume, 2004). Ammonia pressurization at 1 g/g of bagasse in a reactor in liquid phase for 5 minutes at 50 percent bagasse moisture resulted in maximum solubulization of lignocellulosic contents, leading to enhanced value of bagasse as feed substrate in animals (Pernalete *et al.*, 2008). Steam-treated bagasse pith could replace 30 percent of the concentrate component of the diet (15 percent of total diet) without any negative effect on physiological and productivity parameters (body weight changes in ewes and lambs, milk composition, blood parameters) in pre- and post-lambing Lorie ewes, over a period of 120 days (Ebrahimi *et al.*, 2009).

Alkali or acid treatment

Alkali or acid treatment of lignocellulosic material has been quite widely used by different workers to improve the nutritive value of fibrous feed stuff. Ensiling of green sorghum alone or with 20 percent wheat straw and poultry litter, or 20 percent bagasse with poultry litter, resulted in comparable dry matter, protein and fat digestibility between the animal groups fed three types of ensiled diets. The digestible crude protein (DCP) and TDN of sorghum silage, wheat straw and bagasse-added groups were 2.0, 60.1; 4.3, 45.3; and 6.1, 50.3 percent, respectively (Parthasarathy and Pradhan, 1982). Tudor and Inkerman (1986) reported an increase in organic matter digestibility *in vitro* from 28 to 63 percent in sugar cane bagasse with increasing concentrations of NaOH. Supplementation of black liquor, an effluent containing NaOH (10.5 g/litre) from the paper industry to bago-molasses and ensiling for 90 days (bagasse:molasses mixed in a 10:1 ratio and DM adjusted to 70%) resulted in higher digestibility of lignocellulosic materials in male buffalo calves (Prasad and Prasad, 1986). Nour and El-Tourky (1987) reported that treatment of bagasse or sugar cane pith with 5 percent NaOH and supplemented with cottonseed cake resulted in improvement in the intake and digestibility of nutrients, and better nutritive value of diets in Rahmany rams, compared with those fed untreated bagasse. Further, the productive performance of animals fed a pith-containing diet was better than bagasse-containing diets.

The response in Holstein bulls fed corn brewers grain-bagasse silage with alfalfa pellets versus concentrate with alfalfa pellets resulted in comparable growth rates, nutrient digestibility and carcass traits with economic advantage in bagasse-fed groups. However, there were differences in the blood parameters (Su and Yan, 1998a). The use of distillers corn brewers grain-bagasse silage with alfalfa pellets versus concentrate with alfalfa pellets in crossbred goats resulted in similar weight gains, nutrient digestibility, blood parameters and carcass traits, with economic advantage in the bagasse-fed group (Su and Yan, 1998b). The feed intake, digestibility of nutrients, carcass characteristics and blood parameters did not differ between the groups of yellow cattle fed either distillers rice grain with bagasse silage and concentrate or Pongola grass silage and concentrate, with the feed cost per kg of liveweight gain was more economic in the bagasse-based silage-fed group (Su and Yan, 2000). Odai *et al.* (2002) reported that bagasse silage can be kept for at least 90 days and then used as a source of roughage for dairy cattle during the dry season. A combination of 25 percent each of bagasse and rice straw and 50 percent brewer's grains can be used for fattening beef cattle. Yong and Zhou (2002) reported that treatment of bagasse with 5 or 7 percent hydrogen peroxide, urea + $Ca(OH)_2$, or Urea + NaOH increased the degradation rate and fibre degradation index, while the treatment with urea alone could not achieve the same effect. Calcium hydroxide treatment at 8 percent of bagasse dry matter decreased the contents of NDF, ADF and lignin by 23, 5 and 7 percent, respectively, while the *in vitro* digestibilities of DM and neutral-detergent fibre (NDF) increased by up to 60 percent. It was concluded that calcium hydroxide treatment can enhance the fermentation of sugar cane bagasse by rumen micro-organisms, and is most effective at 5.1–6.5 percent of dry bagasse (Guo and Meng, 2006). Nasuer, Chaudhry and Khan (2006), reported that urea treatment of bagasse should always include a source of urease to enhance the utilization of the crude protein content of the treated bagasse.

Studies in lactating buffaloes using four different roughage sources: (1) maize silage; (2) a mixture of sugar beet silage and sugar cane bagasse; (3) a mixture of sugar beet silage and wheat straw; and (4) a mixture of sugar beet silage, sugar cane bagasse and wheat straw, resulted in comparable milk yield, fat and solids-not-fat content. The cost of feeding for the group fed a mixture of sugar beet silage and sugar cane bagasse was found to be significantly lower than the other treatments on a 4 percent fat-corrected milk basis (Ebrahim, Reza and Hassan, 2008).

Biological treatment

While many studies have been conducted on the physical (steam) and chemical (acid or alkali) treatments of bagasse, there is little literature available on the biological treatment of bagasse, using lignolytic fungi through solid state fermentation. Bagasse is considered to be an ideal substrate for applications of microbial fermentations for the production of value-added products because of its rich organic content (Zadrazil and Puniya, 1996). Solid state fermentation with *Pleurotus sajur-caju* for 30 days in a chain of flasks resulted in significant improvement in digestibility of bagasse, from 45 to 63 percent (Puniya *et al.,* 1996). Biological treatment of bagasse with *Lentinula edodes,* a white rot fungus, for 12 weeks improved the *in vitro* organic matter digestibility from 45.6 to 68.6 percent (Okano *et al.*, 2006). Microbial fermentation of bagasse for 21 days, using chicken dropping (10 percent) improved its digestibility to the extent that it could be utilized as an alternative livestock feed (Anakalo, Abdul and Anakalo, 2009).

Pre-treatment of fibrous crop residues has been most widely studied and documented approach for improving the nutritive value, while physical, chemical and biological approaches, or a combination, have improved the digestibility of bagasse and pith. Treated bagasse or pith in most of the reports had a positive effect on the digestibility and production response in different species. Treated bagasse can be used to replace the conventional feed resources, augmenting other locally available feed resources, and can also be used to cut down feeding costs as bagasse is usually cheaper than other feed resources. Up-scaling of treatments to commercial scale, and the cost efficiency of these approaches, are the major factors in determining the practical application of the treatment approaches in utilizing bagasse. Studies on these aspects are virtually non-existent.

Supplementation of bagasse

Sugar cane bagasse can only provide a basal diet and it has to be supplemented with other, high quality feed resources to maintain and promote desired levels of production (milk, meat, draught, reproduction). The nature and quantity of supplements would be determined by a number of factors; of these, the level of production, nature of the supplement, cost of the supplement and produce value are important parameters. Of all the supplements, urea and molasses have been tried most extensively due to ready availability of molasses at sugar plants and low cost of urea. Kaushal, Kochar and Chopra (1972) observed that the soluble carbohydrate contents of factory bagasse did not supply sufficient energy for proper utilization of the urea in Sahiwal calves. Increasing levels (5 to 40% of diet) of alkali-treated bagasse (treated with 4 or 6% urea) together with molasses, resulted in decreased dry matter digestibility in sheep, with 4 percent alkali treatment found to be a better level. Furthermore, between sheep and goats fed 20 and 40 percent bagasse, goats were found to be able to digest significantly more fibre than sheep (Devendra, 1979)

Enriched bagasse with urea (2%) and molasses (20%) with or without alkali (4%) fed *ad libitum* to crossbred bulls with limited concentrate resulted in similar feed intake and digestibility of dry matter, protein and fat (Vaidya, Reddy and Mohan, 1981). Alkali treatment of bagacillo (the short fibre of sugar cane bagasse) at 6 percent NaOH with 20 percent moisture in the finished product, when fed with molasses resulted in higher weight gain, fibre digestibility and increased nitrogen retention than in the untreated bagacillo fed lambs. The superior performance of the lambs on the treated bagasse diet was attributed to its higher palatability (Chicco *et al.*, 1983). Crossbred bulls fed sugar cane bagasse-based complete feeds consisting of 5 kg of green maize and molasses (1–2 kg/day) over a period of 5 months resulted in satisfactory semen production and sperm concentration (Bhosrekar *et al.,* 1988). Use of pith as a "Molasses urea and pith" mixture in cattle diets up to 30 percent of the concentrate, replacing coconut cake totally, resulted in comparable quality and palatability of feed, body weight gain and feed efficiency. It was concluded that pith used as a "Molasses urea pith" mixture can substitute for coconut meal as a protein source in the concentrate for beef cattle (Wardhani *et al.*, 1985). Based on the series of experiments conducted in Taiwan over a period of 10 years, Wang (1986) concluded that feed cost can be reduced by utilizing sugar co-products such as cane top, bagasse, bagasse pith, molasses and processed sugar co-products

Huang *et al.* (1993) reported that bulls fed a diet containing 34 percent sugar cane bagasse, together with concentrates, wherein soybean oil soap stock partially replaced cane molasses, over a period of 97 days could result in daily weight gains of around 1 kg. Sugar cane bagasse supplemented with 15 percent molasses and urea or poultry manure was as good as grass hay in crossbred goats fed 1 kg concentrate daily in supporting milk production and body weights over a period of 90 days (Sanchez and Garcia, 1994). Bagasse and sawdust-based poultry litter can replace up to 30 percent nitrogen in conventional concentrate mixture given with wheat straw to maintain adult crossbred cattle and Murrah buffaloes (Parthasarathy and Pradhan, 1994).

Reddy, Reddy and Nagalakshmi (2001) reported that sugar cane bagasse can be used as a sole roughage source at 40 percent of the diet containing 60 percent concentrate and converted into total mixed rations in pelleted as well as in mash form. As a total mixed ration diet, the digestibility was significantly improved compared with conventional diets containing 40 percent bagasse. Haque and Rahman (2002) reported that bagasse supplemented with 2 percent urea *vs* a group fed urea-molasses-straw resulted in lower feed intake and significantly lower digestibility, but had no significant effect on daily weight gains in indigenous bulls.

Supplementation of yeast in pelleted sugar cane bagasse feed in fattening sheep significantly improved the average daily gain (ADG) without affecting the dry matter intake (DMI), blood profile or carcass characteristics (Monjeghtapeh and Kafilzadeh, 2008). An economic analysis conducted by Cabello, Torres and Almazan (2008) to compare the economic viability for milk production of a diet based on bagasse, revealed that the net value of bagasse was in the range of US$ 20–30/tonne, being lower than the net value of bagasse for electricity generation at sugar mills. Similarly, the calculations revealed that blackstrap molasses gives negative revenue when used for fattening cattle in comparison with its export price for ethanol production.

The success of supplementation strategies are mainly dependent on the volume and price structure of the supplements to support a given level of production, besides the quality of the basal roughage. Low nutrient density and digestibility of bagasse necessitates a reasonably good level of concentrate supplements to support various productive functions in livestock. Besides the supplement need, the form of feed, e.g. total mixed ration in the form of feed blocks or complete feed mash, can improve the nutrient utilization, as evident from some of the above studies. Furthermore, using locally available supplements, such as sugar cane tops or molasses, could make the feeding economic and promote the use of bagasse.

Further studies on responses in different categories of livestock fed untreated or processed bagasse are summarized in Table 4.

From the findings reported by different workers (Table 4) on the responses recorded from livestock fed treated and untreated bagasse, certain generalizations can be made. First, bagasse is a low quality roughage and it cannot be fed as sole diet to ruminants and must be supplemented with nitrogen, energy and minerals to sustain the animals. Second, the proportion of bagasse and supplements are dictated by production levels. In low and medium producers, bagasse can be fed up to 40–60% of the diet, provided the concentrate supplement is balanced properly to fulfil the animals requirements. Finally, a balanced bagasse-based diet can probably reduce the cost of feeding for milk and meat production, particularly when straw prices are high.

KNOWLEDGE GAPS AND FUTURE RESEARCH NEEDS

The bulky and fibrous nature of bagasse makes it a poor roughage source and most of the times it has to be used locally. Its efficient use is directly linked to quality, cost and local availability of other feed supplements. Keeping in view the availability of feed resources and the production levels of animals in a particular area, there is a need to develop region-specific feeding regimens for different productive functions, integrating the sugar cane co-products (sugar cane tops, bagasse and molasses) with locally-available resources, for optimizing livestock production.

Furthermore, in view of the ongoing research activities on second-generation biofuels, where the use of complex carbohydrates trapped in crop residues are used as sources of ethanol production through appropriate pre-treatments, one can only hope that such studies may provide a lead to newer approaches for effective delignification of bagasse to improve its feeding value. The current need is for economic analysis and feasibility studies of the options for using sugar cane bagasse (treatments, supplementation, complete feed, etc.) for feeding livestock vs biofuel and non-feed uses. This should be undertaken through pilot projects, through field size operations and not laboratory-scale experiments, under various circumstances, to better understand the feasibility of various approaches (processing, supplementation) to using bagasse for livestock feeding.

CONCLUSIONS

Considerable information is already available on the nutritive value of bagasse and the different approaches that have been adopted to improve its nutritional quality. Thus, the use of bagasse with different supplements for various productive functions in several species has been well documented. In general, the treated bagasse can be safely used up to 30–40 percent in ruminant diets to support a medium

TABLE 4
Summary of reported responses in different categories of livestock fed untreated or processed bagasse

Treatment	Species and response	Remarks	Reference
Untreated bagasse/pith			
Bagasse with molasses mixture at 10, 20 and 30% replacing maize	Pigs (local and exotic breeds)	ADG, DMI and FCR were significantly lower in pigs given 30% mixture.	Reddy *et al*., 1985.
Untreated bagasse (UB)	Bulls fed complete feed blocks containing 40% wheat straw or UB	Rumen fermentation in sugar cane bagasse fed diet was comparable to wheat straw based diet	Hozhabri and Singhal, 2006.
Complete feeds (i) 30% Untreated bagasse + 70% unconventional concentrates (ii) 30% wheat straw + 70% concentrate	Crossbred calves fed for 40 weeks. DMI and ADG were comparable in both groups	Complete feed with 30% sugar cane bagasse and non-conventional feeds was economical	Pandya *et al*., 2009.
Complete feeds (i) 40% wheat straw + 60% concentrate (ii) 40% untreated bagasse + 60% concentrate	Crossbred calves fed for 4 months	DMI, ADG and FCR were comparable between the groups, with bagasse diets being economical	Fardin and Singhal, 2009.
Steam treated bagasse and pith			
Steam pressure treated bagasse	Milch cows fed for 28 days, replacing 18–32% in complete diets	Greatly depressed DMI, milk yield and milk fat content	Horn *et al*., 1984.
Steaming of bagasse at 170–195 °C for 60 minutes. + NaOH addition @ 5% on DM basis	Improved the DM digestibility from 27–30% to 52% in sheep Further improved the digestibility to 65–66% in sheep	Palatability was impaired	Ali, 1991.
Steam treated bagasse supplemented with legumes, urea molasses, rice bran and poultry litter	Crossbred bulls fed for141 days	Steam-treated bagasse was well consumed and ADG varied from 0.57 to 0.75 kg	Héctor, 1990.
Steam treatment of bagasse followed by anhydrous ammonia treatment (3% by weight) for 15 days, plus supplements.	Crossbred bulls fed for169 days	ADG in bulls fed steam treated bagasse (0.64 to 0.54 g) was significantly higher than the steam-ammonia treated bagasse (0.30 g)	Héctor, 1990.
Steam treated pith (STP)	Arabi lambs fed for 70 days. STP constituted 0, 11, 22 and 33% of diet and replaced barley at 0, 25, 50 and 75%, respectively	DMI and ADG did not differ. FCR was significantly lower at 33% of STP. STP at 11% level had the best economic efficiency	Ensiyeh, Najafgholi and Hamideh, 2009.
Chemical treatments			
(i) Complete diets containing 40% alkali treated (2% NaOH) bagasse (ATB) (ii) Complete diets containing 40% untreated bagasse (UB) (iii) Control: pasture + concentrates @ 360 g/liter milk	Lactating cows fed for 300 days Feed consumption- (i) 16.5 kg, (ii) 14.2 kg and (iii) 6 kg concentrate + pasture. Milk production kg – (i) 17.2 (ii) 12.5 and (iii) 16.5	UB resulted in significant drop in milk production. ATB was comparable to controls in milk production but it resulted in significant drop in milk fat and total solids %	Randel *et al*., 1972.
(i) urea-molasses enriched sugar cane bagasse (ii) (i) with alkali treatment (iii) 4 kg green + paddy straw	Crossbred heifers fed for 61 days All three roughages were fed ad libitum with 2 kg concentrate	ADG g (i) 158 (ii) 55 & (iii) 356 Urea-molasses enriched bagasse, without or with alkali treatment was not suitable as the only source of roughage.	Reddy, Mohan and Das, 1981.
Untreated and alkali-treated (5% NaOH solution) bagasse	Awassi lambs 25, 40 and 50% untreated and alkali-treated bagasse	Treatment had no significant effect on ADG and FCR NaOH treatment appeared mainly to increase its palatability leading to higher ADG	Al-Tawash and Alwash, 1983.
Steam and alkali treated bagasse (ATB)	Dohne Merino lambs fed to appetite for 56 days. ATB improved ADG and FCR at 19 and 40% inclusion levels.	Steam treatment improved performance at lower inclusion level, while at higher levels it had a negative effect.	Jacobs and van Niekerk, 1985.
(i) Spray drying of fresh bagasse with NaOH solution (30%) containing 5% NaOH of dry fibre (TAB). (ii) Supplementation of (i) with molasses (20: 40 w:w) and urea (1.5 to 2.0%) (iii) supplementation of (ii) with cotton seed	Increased IVDMD from 30 to 55% Maintained weaner cattle Daily gain up to 0.7 kg in growing cattle	TAB can be stored up to 6 months without problem. No health problems associated with the feeding TAB-based diets provided the concentration of NaOH does not exceed 5% on dry fibre.	Tudor and Inkerman, 1989.
Raw bagasse pith (RBP) and urea ammoniated bagasse pith (UABP) (4% urea, 40% moisture and 21 days treatment)	Crossbred bulls fed for 28 days Complete feeds having 50 : 50 roughage and concentrate	RBP was inferior to wheat straw and UABP was superior to wheat straw based diets	Singh *et al*., 2004.

TABLE 4 (Cont'd)

Treatment	Species and response	Remarks	Reference
Complete feed pellets containing 50% concentrate and (i) Urea-ammoniated bagasse (UAB) 50%, or (ii) Tree leaves 50%	Goat kids fed for 90 days. ADG – (i) 68.7 g and (ii) 44.1 g FCR – (i) 8.6 and (ii) 10.8	UAB Improved performance, rumen fermentation and blood biochemical characteristics	Dhore *et al*., 2006.
Complete feed containing 60% concentrate, 20% wheat straw and 20% Urea ammoniated bagasse –UAB	Crossbred bulls fed for 30 days	No adverse affects	Tiwari, Garg and Singh, 2006.
Concentrate 500 g/day + *ad libitum* 1% urea treated: (i) wheat straw (control) (ii) sugar cane tops (T1) (iii) bagasse (T2)	Said rams were fed for 90 days and used for breeding. ADG, testicular size, scrotal circumference and semen characteristics increased significantly in T1 and T2.	Pregnancy rates in groups (i), (ii) and (iii) were 74.1, 86.7 and 81.5%, respectively, suggesting that urea-treated sugar cane tops and bagasse was better than wheat straw.	Megahed and Etman, 2006.
Urea fortified bagasse pith + sugar cane bagasse with 15% molasses	Holstein lactating cows fed for 75 days, replacing 0, 40, 50, 60 or 70% of alfalfa	Milk yields in 0, 40, 50, 60 and 70% replacement were 15.3, 14.5, 14.4, 14.1 and 13.4 kg milk/day. Feed cost at 60% replacement was most economical.	Ahmad, 2009.
Biological treatment			
Acid/grinding/enzymatic hydrolysis followed by culturing of *Geotrichum candidum* or *Oidium lactis* of bagacillo(1)	Fish. Feeding the granulated product replacing 60% of concentrate	Improved the WG and FCR in grass carp	Yu, 1990.
Solid state fermentation using ligninolytic white-rot fungus, *Lentinus edodes*	Sheep Degradation of lignin was 34.4%,	Increase of 34.3% digestibility in sheep and the material was free from toxins	Pham and Ramirez, 1996.
Basal diet of Bermuda hay supplemented with *ad libitum* (i) Fermented bagasse feed - Solid state fermentation of bagasse with wheat bran (w/w) in 1:3 using *Aspergillus sojae* (ii) Lucerne hay cubes	Crossbred bucks fed for 196 days WG, DMI, FCR, DCP and TDN intakes were comparable to groups fed Lucerne hay. Sensory attributes of meat were superior in bagasse-fed group	Fermented bagasse feed could be an alternative to Lucerne hay cube and thereby reduce the feeding cost	Ramli *et al*., 2005.
Combination of approaches			
(i) Untreated bagasse + GNC (ii) Steam-treated bagasse (7 kg/cm2) + GNC (iii) Alkali-treated bagasse (4% NaOH – 1 litre/kg) + GNC	Bull calves fed for 51 days	(i) DMI: 1.9 kg, ADG: 124 g/day and DM digestibility: 53.8% (ii) DMI: 4.2 kg, ADG: 385 g/day and DM digestibility-60.0% (iii) DMI: 2.3 kg, ADG: 182g/day and DM digestibility: 62.8%	Joshi *et al*., 1984.

Notes: (1) Bagacillo is the waste from paper manufacture using sugar cane bagasse. ADG = Average daily gain; DMI = Dry matter intake; FCR = Feed conversion ratio; UB = Untreated bagasse; UAB = Urea-ammoniated bagasse; STP = Steam-treated pith; ATB = Alkali-treated bagasse; WG = Weight gain; DCP = Digestible crude protein; TDN = Total digestible nutrients; GNC = Groundnut cake; RBP = Raw bagasse pith; UABP = Urea-ammoniated bagasse pith; TAB = Treated alkaline bagasse.

level of production. With better quality supplements or processing, the level of bagasse in the diet of low producers could be increased, even up to 60%. Steam treatment, alkali treatment and supplementation with urea, molasses and locally available concentrate sources have been quite effective in improving the utilization of bagasse as ruminant feed. Bagasse as such is not harmful, but steam treatment in the presence of certain chemicals, especially alkali at higher levels, can induce certain changes that may prove harmful to animals. So one has to be careful in combining steam treatment of bagasse with other chemical treatments. However, most of the bagasse generated at sugar processing units at present continues to be primarily used for fuel purposes, and the practice of feeding bagasse to livestock is very limited and at times only seasonal. The ongoing "livestock revolution" of greater demand for livestock products, resulting in greater demand for feed resources, and thus increasing the cost of feed resources, both roughages and concentrates, are some of the factors that could have a positive impact on the use of bagasse for livestock feed. National policies favouring energy security, leading to greater emphasis on biofuels, and providing tax incentives and subsidies to the energy sector could favour the diversion of this potential feed resource, namely bagasse, to non-feed uses.

BIBLIOGRAPHY

Ahmad, K. 2009. The use of urea-treated sugar cane bagasse in dairy cow nutrition. Khuzestan Agricultural and Natural Resources Research Centre, Khuzestan, Iran (Islamic Republic of) .

Al-Tawash, M.Y. & Alwash, A.H. 1983. The effect of the level of raw and alkali-treated sugar cane bagasse on the digestibility of the rations and performance of Awassi lambs. *World Review of Animal Production*, 19(2): 25–29.

Alexander, A.G. 1988. Sugar cane as a source of biomass. pp. 46–60, *in: Sugar cane as feed.* Proceedings of an Expert

Consultation on the Use of Sugar Cane as Feed, Santo Domingo, Dominican Republic, 7–11 July 1986. *[FAO] Animal Production and Health Paper*, no. 72. 319 p. Available at http://www.fao.org/ag/AGa/AGAP/FRG/AHPP72/ahpp72.htm Accessed 16 October 2011.

Ali, A. 1990. Treatment of sugar cane bagasse for improving its nutritive value. *Technical Bulletin, Food and Fertilizer Technology Center*, no. 95. 10 p.

Ali, A. 1991. Treatment of sugar cane bagasse for improving its nutritive value. *Progressive Farming*, 11(1): 56–61.

Anakalo, S., Abdul, F. & Anakalo, M.G. 2009. Enhancement of the nutritive value of bagasse using chicken manure. *African Journal of Food, Agriculture, Nutrition and Development*, 9(8): 1712–1724.

Bhosrekar, M.R., Thole, N.S., Joshi, A.L., Purohit, J.R., Pande, A.B. & Mangurkar, B.R. 1988. Performance of crossbred bulls fed bagasse-based complete diet. *Indian Journal of Animal Sciences,* 58(5): 619–622.

Cabello, A., Torres, A. & Almazan, O. 2008. The economical viability of animal production based on sugar cane co-products under the present prices of commodities. *Sugar Technology*, 10(1): 25–28.

Chicco, C.F., Garcia, G., Fernandez, C. & Prays, C.R. 1983. Cane molasses and NaOH-treated bagacillo diets for lambs. *South African Journal of Animal Science,* 13(1): 18–20.

de La Cruz, H.O. 1990. Steam treated bagasse for fattening cattle. Effect of supplementation with *Gliricidia sepium* and urea/molasses. *Livestock Research for Rural Development,* 2(2).

Devendra, C. 1979. The digestibility of chemical treated bagasse by sheep and goats. *MARDI Research Bulletin,* 7(2): 103–115.

Dhage, S.A., Fulpagare, Y.G., Jagtap, D.Z. & Kandalkar, Y.B. 2009. Nutritive value of whole sugar cane based ration in lactating crossbred Phule Triveni cow. *Indian Journal of Animal Nutrition,* 26(3): 229–232.

Dhore, R.N., Chavan, G.V., Shital Chopde & Dhok, A.P. 2006. Evaluation of urea treated sugar cane bagasse-based pelleted complete ration in goats. *Indian Journal of Small Ruminants*, 12(2): 179–184.

Ebrahim, F.N., Reza, M.M. & Hassan, F. 2008. The effects of beet pulp, sugar cane bagasse and wheat straw silage on the performance of lactating buffaloes. Animal Science Research Institute, Karaj, Iran (Islamic Republic of).

Ebrahimi, R., Eslami, M., Fayazi, J. & Jahrom, M.F. 2009. Effect of feeding steam treated pith bagasse on body change weight, milk constituents and blood parameters of Lori ewes in Khouzestan Province, Iran (Islamic Republic of). *Pakistan Journal of Nutrition*, 8(12): 1915–1919.

Ensiyeh Hashemipour, Najafgholi Dabiri & Hamideh Hashemipour. 2009. Effect of diets containing different levels of steam treated pith bagasse on performance and carcass characteristics of fattening Arabi lambs. *Journal of Animal and Veterinary Advances*, 8(11): 2139–2142.

FAO [Food and Agriculture Organization of the United Nations]. 1988. *Sugar cane as feed.* Proceedings of an Expert Consultation on the Use of Sugar Cane as Feed, Santo Domingo, Dominican Republic, 7–11 July 1986. *[FAO] Animal Production and Health Paper*, no. 72. 319 p. Available at http://www.fao.org/ag/AGa/AGAP/FRG/AHPP72/ahpp72.htm Accessed 16 October 2011.

Fardin Hozhabri & Singhal, K.K. 2009. Influence of roughage sources and protected protein in complete feed block on nutrients utilization, growth performance, microbial protein synthesis and body composition in crossbred calves. *Indian Journal of Animal Nutrition*, 26(4): 297–305.

Fontana, J.D., Ramos, L.P. & Deschamps, F.C. 1995. Pretreated sugar cane bagasse as a model for cattle feeding. *Applied Biochemistry and Biotechnology Part A, Enzyme Engineering and Biotechnology,* 51/52: 105–116.

Guo, W.S. & Meng, Q.X. 2006. Effect of treatment of sugar cane bagasse with calcium hydroxide on its chemical components and ruminal fermentation traits *in vitro*. *Journal of China Agricultural University,* 11(3): 65–69.

Hamad, M. A. & El-Saied, H. 1982. The ammoniation of agricultural residues. *Journal of the Science of Food and Agriculture,* (33)3: 253–254.

Helmling, O., Arnold, G., Rzehak, H., Fahey, G.C. Jr., Berger, L.L. & Merchen, N.R. 1989. Improving the nutritive value of lignocellulosics: the synergistic effects between alkaline hydrogen peroxide and extrusion treatments. *Biotechnology and Bioengineering*, (33)2: 237–241.

Horn, H.H. van., Harris, B. Jr, Taylor, M.J., Bachman, K.C. & Wilcox, C.J. 1984. By-product feeds for lactating dairy cows: effects of cottonseed hulls, sunflower hulls, corrugated paper, peanut hulls, sugar cane bagasse and whole cottonseed with additives of fat, sodium bicarbonate and *Aspergillus oryzae* product on milk production. *Journal of Dairy Science*, 67(12): 2922–2938.

Hozhabri, F. & Singhal, K.K. 2006. Effect of incorporation of sugar cane bagasse and formaldehyde treated mustard cake in wheat straw based complete feed block on rumen fermentation pattern and outflow rate of digesta in crossbred bulls. *Indian Journal of Dairy Science,* 59(4): 239–244.

Huang, M.D., Chen, K.H., Kou, C.C., Chen, K.P., Kou, P.W., Huang, H.Y., Liou, W.T. & Chen,Y.C. 1993. Soybean oil soap stock as a part substitute for sugar cane molasses for growing finishing beef cattle. pp. 101–108, *in:* Research Report, Animal Industry Research Institute, Taiwan Sugar Corporation.

Haque, K.S. & Rahman, M.M. 2002.Utilization of sugar cane tops and bagasse as roughage sources in growing bulls. *Indian Journal of Animal Nutrition*, 19(3): 227–231.

Jacobs, G.A. and van Niekerk, B.D.H. 1985. Sodium and steam-treated sugar cane bagasse in low and high fiber fattening diets for lambs. *South African Journal of Animal Science*, 15(4): 166–168.

Joshi, A.L., Rangnekar, D.V., Badve, V.C. & Waghmare, B.S. 1984. Utilization of bagasse treated with steam and sodium hydroxide by crossbred calves. *Indian Journal of Animal Sciences,* 54(2): 149–152.

Kaushal, J.R., Kochar, A.S. & Chopra, A.K. 1972. Effect of residual carbohydrates of factory bagasse on the utilization of urea in ruminants. *Indian Journal of Animal Sciences,* 42(6): 399–401.

Kewalramani, N., Kamra, D.N., Lall, D. & Pathak, N.N. 1988. Bioconversion of sugar cane bagasse with white rot fungi. *Biotechnology Letters,* 10(5): 369–372.

Kling, S.H., Neto, C.C., Ferrara, M.A., Torres, J.C.R., Magalhaes, D.B. & Ryu, D.D.Y. 1987. Enhancement of enzymatic hydrolysis of sugar cane bagasse by steam explosion pre-treatment. *Biotechnology and Bioengineering*, 29(8): 1035–1039.

Krishnamoorthy, U., Singh, K.C. & Kailas, M.M. 2005. Evaluation of roughages for rumen microbial biomass synthesis. *Indian Veterinary Journal,* 82(4): 453–454.

Megahed, G.A. & Etman, A.H.M. 2006. Effects of agricultural byproducts in ration on productive and reproductive performance of Saidi rams. *Acta Veterinaria,* 75: 22–27.

Monjeghtapeh, S.S. & Kafilzadeh, F. 2008. Microbial direct-fed in small ruminant nutrition. P-004, *in: Agricultural and biosystems engineering for a sustainable world*. International Conference on Agricultural Engineering, Hersonissos, Crete, Greece, 23–25 June 2008.

Nagalakshmi, D. & Reddy, D.N. 2010. Effect of feeding expander extruded processed complete diet containing sugarcane bagasse on performance of Murrah buffaloes. *Animal Nutrition and Feed Technology*, 10(1): 1–8.

Naseeven, M.R. 1988. Sugar cane tops as livestock feed. pp. 106–122, *in: Sugar cane as feed.* Proceedings of an Expert Consultation on the Use of Sugar Cane as Feed, Santo Domingo, Dominican Republic, 7–11 July 1986. *[FAO] Animal Production and Health Paper*, no. 72. 319 p. Available at http://www.fao.org/ag/AGa/AGAP/FRG/AHPP72/ahpp72.htm Accessed 16 October 2011.

Nasuer, Z., Chaudhry, S.M. & Khan, M.F.U. 2006. A laboratory assessment of various urease sources on the chemical composition of urea-treated sugar cane bagasse. *Pakistan Journal of Agricultural Sciences*, 43(3/4): 169–172.

Nour, A.M. & El-Tourky, M. 1987. Sugar cane and its co-products in animal feeding. 3. Utilization of co-products of sugar cane industry in the diets of sheep. *Alexandria Journal of Agricultural Research,* 32(3): 63–74.

Odai, M., Sumamal, W., Narmsilee, R., Pholsen, P., Chuenpreecha, T. & Indramanee, S. 2002. Development and evaluation of bagasse silage for cattle feed. *JIRCAS Working Report,* 30: 167–171.

Okano, K., Iida,Y., Samsuri, M., Prasetya, B., Usagawa,T. & Watanabe,T. 2006. Comparison of *in vitro* digestibility and chemical composition among sugar cane bagasse treated by four white-rot fungi. *Animal Science Journal,* 77(3): 308–313.

Pandya, P.R., Desai, M.C., Patel, G.R., Talpada, P.M., Pande, M.B. & Parnerkar, S. 2009. Economical rearing of crossbred calves on complete feeds, based on sugar cane bagasse and non-conventional feeds. *Indian Journal of Animal Nutrition,* 26(3): 211–215.

Parthasarathy, M. & Pradhan, K. 1982. Fermentation characteristics and feeding value of ensiled poultry litter containing wheat straw, bagasse or sawdust. *Animal Feed Science and Technology,* 7(4): 341–349.

Parthasarathy, M. & Pradhan, K. 1994. Comparative utilization of poultry-litter-containing rations by crossbred cattle and Murrah buffaloes. *Buffalo Bulletin,* 13(4): 90–93.

Pate, F.M. 1982. Value of treating bagasse with steam under pressure for cattle feed. *Tropical Agriculture,* 59(4): 293–297.

Paturau, J.M. 1988. Alternative uses of sugar cane and its byproducts in agro-industries. pp. 24–45, *in: Sugar cane as feed.* Proceedings of an Expert Consultation on the Use of Sugar Cane as Feed, Santo Domingo, Dominican Republic, 7–11 July 1986. *[FAO] Animal Production and Health Paper*, no. 72. 319 p. Available at http://www.fao.org/ag/AGa/AGAP/FRG/AHPP72/ahpp72.htm Accessed 16 October 2011.

Pernalete, Z., Pina, F., Suarez, M., Ferrer, A. & Aiello, C. 2008. Fractionation of sugar cane bagasse by ammonia treatments: effect of bagasse moisture and ammonium dose. *Bioagro*, 20(1): 3–10.

Pham, C.B. & Ramirez, J. 1996. Bio-delignification of sugar cane residues to increase the digestibility for ruminants feeding. Paper presented at the Asia-Pacific Biotechnology Congress, Makati City, The Philippines, 22–24 May 1996.

Prasad, J.R. & Prasad, D.A.1986. Nutrient utilization in buffalo calves on feeding black-liquor treated bago-molasses with or without ensiling. *Indian Journal of Animal Nutrition*, 3(4): 229–232.

Preston, T.R. 1980. A model for converting biomass (sugar cane) into animal feed and fuel. *In:* Animal Production Systems for the Tropics. International Foundation for Science, Stockholm, Publication No. 8.

Preston, T.R. 1988. Fractionation of sugar cane for feed and fuel. pp. 310-319, *in: Sugar cane as feed.* Proceedings of an Expert Consultation on the Use of Sugar Cane as Feed, Santo Domingo, Dominican Republic, 7–11 July 1986. *[FAO] Animal Production and Health Paper*, no. 72. 319 p. Available at http://www.fao.org/ag/AGa/AGAP/FRG/AHPP72/ahpp72.htm Accessed 16 October 2011.

Preston, T.R. & Leng, R.A. 1984. Supplementation of diets based on fibrous residues and co-products. pp. 373-413, *in:* F. Sundstol and E.C. Owen (editors). *Straw and Other Fibrous By-products as Feed*. Elsevier Press, Amsterdam, The Netherlands.

Puniya, A K., Shah, K.G., Hire, S.A., Ahire, R N., Rathod, M.P. & Mali, R.S. 1996. Bioreactor for solid-state fermentation of agro-industrial wastes. *Indian Journal of Microbiology*, 36(3): 177–178.

Ramli, M.N., Higashi, M., Imura, Y., Takayama, K. & Nakanishi, Y. 2005. Growth, feed efficiency, behavior, carcass characteristics and meat quality of goats fed fermented bagasse feed. *Asian-Australasian Journal of Animal Sciences*, 18(11): 1594–1599.

Randel, P.F., Ramirez, A., Carrero, R. & Valencia, I. 1972. Alkali-treated and raw sugar cane bagasse as roughages in complete rations for lactating cows. *Journal of Dairy Science,* 55(10): 1492–1495.

Rangnekar, D.V. 1988. Integration of sugar cane and milk production in Western India. pp. 176–187, *in: Sugar cane as feed.* Proceedings of an Expert Consultation on the Use of Sugar Cane as Feed, Santo Domingo, Dominican Republic, 7–11 July 1986. *[FAO] Animal Production and Health Paper*, no. 72. 319 p. Available at http://www.fao.org/ag/AGa/AGAP/FRG/AHPP72/ahpp72.htm Accessed 16 October 2011.

Rangnekar, D.V., Badve, V.C., Kharat, S.T., Soble, B.N. & Joshi, A.L. 1982. Effect of high pressure steam treatment on chemical composition and *in vitro* digestibility of roughages. *Animal Feed Science and Technology,* 7: 61–70.

Rangnekar, D.V., Joshi, A.L., Badve, V.C. & Thole, N.S. 1986. Summary of studies on steam treatment of sugar cane bagasse for feeding of dairy cattle. Presented at the International Workshop on Rice Straw and Related Feeds in Ruminant Rations, Kandy, Sri Lanka, 24–28 March 1986.

Reddy, D.V., Prasad, D.A., Charulu, E.K., Reddy, M.R.N. & Audeyya, P. 1985. Effect of replacing maize with bagasse and molasses mixture (w/w) on growth and digestibility coefficients in Desi pigs. *Cheiron*, 14(1): 1–7.

Reddy, M.R., Mohan, D.V.G. & Das, C.T. 1981. Effect of feeding urea-molasses enriched sugar cane bagasse with or without alkali treatment as the sole source of roughage for growing cross-bred calves. *Indian Journal of Animal Research,* 15(1): 9–14.

Reddy, G.V.N., Reddy, K.J. & Nagalakshmi, D. 2001. Nutrient utilization and rumen fermentation pattern of sugar cane bagasse based complete diets in buffalo bulls. *Indian Journal of Animal Nutrition,* 18(2): 138–145.

Rivers, D.B. 1988. Factors affecting the enzymatic hydrolysis of bagasse and rice straw. *Biological Wastes*, 26(2): 85–95.

Rolz, C., de Arriola, M.C., Valladares, J. & de Cabrera, S. 1987. Effects of some physical and chemical pre-treatments on the composition, enzymatic hydrolysis and digestibility of lignocellulosic sugar-cane residue. *Process Biochemistry*, 22(1): 17–23.

Sanchez, C. & Garcia, de H.M. 1994. Effect of substitution of grass hay with sugar cane bagasse enriched with molasses and urea or poultry manure on the productive performance of goats. *Zootecnia Tropical*, 12(2): 225–240.

Singh, P., Garg, A.K., Tiwari, R.K. & Agrawal, D.K. 2004. Influence of feeding raw bagasse with urea treated bagasse pith on intake and utilization of nutrients in crossbred bulls. *Indian Journal of Animal sciences,* 74(12): 1223–1226.

Sekiguchi, H., Okubo, T., Goda, Y. & Tohata, R. 1981. Pro Cane for lactating dairy cows. *Bulletin of the Tokyo Metropolitan Livestock Experiment Station,* 18: 1–15.

Su, A.K. & Yan, S.S. 1998a. Effect of corn-brewer's grain-bagasse silage on the growth performance of Holstein bulls. *Journal of Taiwan Livestock Research*, 31(4): 337–344.

Su, A.K. & Yan, S.S. 1998b. Evaluation of corn-brewers' grain-bagasse silage on the growth performance and economic benefit of crossbred goats. *Journal of Taiwan Livestock Research,* 31(4): 345–353.

Su, A.K. & Yan, S.S. 2000. Evaluation of feeding distilled rice grain and bagasse silage on the growth performance of yellow cattle. *Journal of Taiwan Livestock Research,* 33(2): 192–199.

Sundstol, F. 1988. Straw and other fibrous co-products. *Livestock Production Science,* 19(1/2): 137–158.

Tanabe, S. & Kume, S. 2004. Evaluation of the nutritive value of steam-treated sugar cane bagasse. *Bulletin of National Institute of Animal Industry*, 54: 29–34.

Tiwari, R.K., Garg, A.K. & Singh, P. 2006. Effect of cobalt supplementation on nutrient utilization in crossbred cattle fed wheat straw and urea-ammoniated bagasse-based complete feed. *Animal Nutrition and Feed Technology*, 6(2): 185–192.

Tudor, G.D. & Inkerman, P.A. 1986. Intensive production of large ruminants on cassava- or bagasse-based diets. pp. 83–93, *in: Ruminant feeding systems utilizing fibrous agricultural residues*. Proceedings of the 6th Annual Workshop of the Australian-Asian Fibrous Agricultural Residues Research Network, Los-Banos, The Philippines, 1–3 April 1986.

Tudor, G.D. & Inkerman, P.A. 1989. Alkali-treated bagasse – potential as feed for ruminants. pp. 53–66, *in: Recent advances in animal nutrition in Australia*.

Vaidya, K., Reddy, M.R. & Mohan, D.V.G.K. 1981. Utilization of urea-molasses-enriched and/or alkali-treated bagasse as the sole source of roughage for growing cross-bred calves. *Indian Journal of Animal Sciences*, 51(10): 922–925.

Wang, M.T.K. 1986. Research on beef cattle production by the Taiwan Sugar Corporation. Technical Bulletin, Food and Fertilizer Technology Center, no. 95. 10 p.

Wardhani, N.K., Achmanto, Y.P., Musofie, A. & Tedjowahjono, S. 1985. Molasses urea pith mixture as a substitute for coconut oil cake used as protein source in concentrate feed for beef cattle. *Majalah Perusahaan Gula*, 21: 65–70.

Wong, Y., Cheong, Y., d'Espaignet, J.T., Deville, P.J., Sansoucy, R. & Preston, T.R. 1974. The effect of steam treatment on cane bagasse in relation to its digestibility and furfural production. Proceedings of the 15th Congress of ISSCT (South Africa).

Yong, X. & Zhou, X.Q. 2002. The ruminal degradability of fiber carbohydrate in differently treated bagasse. *Journal of Fujian Agricultural and Forestry University,* 31(2): 238–243.

Yadav, R.L. & Solomon, S. 2006. Potential of developing sugar cane co-product-based industries in India. *Sugar Technology*, 8(2/3): 104–111.

Ye, S. & Cheng, J. 2002. Hydrolysis of lignocellulosic materials for ethanol production: a review. *Bioresource Technology*, 83: 1–11.

Yu, B.G. 1990. Protein feed granules from bagacillo for fish farming. *Sugar y Azucar*, 85(11): 30–40.

Zadrazil, F. & Puniya, A.K. 1995. Studies on the effect of particle size on solid state fermentation of sugar cane bagasse into animal feed using white rot fungi. *Bioresource Technology,* 54: 85–87.